Advances in Intelligent Systems and Computing 485

Francisco Rebelo
Marcelo Soares *Editors*

# Advances in Ergonomics in Design

## Proceedings of the AHFE 2016 International Conference on Ergonomics in Design, July 27–31, 2016, Walt Disney World®, Florida, USA

Springer

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Editors

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# Advances in Human Factors and Ergonomics 2016

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***Proceedings of the AHFE 2016 International Conference on Ergonomics in Design, July 27–31, 2016, Walt Disney World®, Florida, USA***

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# Preface

Successful interaction with products, tools, and technologies depends on usable designs and accommodating the needs of potential users without requiring costly training. In this context, this book is concerned with emerging ergonomics in design concepts, theories, and applications of human factors knowledge focusing on the discovery, design, and understanding of human interaction and usability issues with products and systems for their improvement.

This book will be of special value to a large variety of professionals, researchers, and students in the broad field of human modeling and performance who are interested in feedback of devices' interfaces (visual and haptic), user-centered design, and design for special populations, particularly the elderly. We hope this book is informative, but even more—it is thought-provoking. We hope it inspires, leading the reader to contemplate other questions, applications, and potential solutions in creating good designs for all.

The book is organized into nine parts focusing on the following subject matters: Virtual reality challenges, Devices and user interfaces and Digital environment, User studies, Product design and evaluation, and Sustainable design. In the parts that cover Devices and user interfaces the focus is on optimization of user devices, with the emphasis on visual and haptic feedback. In the parts that cover User studies, the focus goes to the limits and capabilities of special populations, particularly the elderly, which can influence the design. Generally, the effect of changes in force and kinematics, physiology, cognitive performance, in the design of consumer products, tools and workplaces is discussed. The parts that cover Virtual reality and Digital environment, Product design and evaluation, and Sustainable design employ a variety of research methods and user-centered evaluation approaches, for developing products that can improve safety and human performance and at same time, the efficiency of the system. Usability evaluations are reported for different kinds of products and technologies.

Part I *Virtual Reality Challenges for the Future of Design*
Part II *Usability and User Experience in Design*
Part III *Human Factors in Design and Management*

Part IV *Ergonomic Design for Industry and Musculoskeletal Disorders (MSD's)*
Part V *Ergonomics in Clothing and Footwear Design*
Part VI *User Research in Design*
Part VII *Information Design*
Part VIII *Assistive Technology in Design*
Part IX *Innovative Design*

We would like to thank the following editorial board members for their contributions.



Lisbon, Portugal — Francisco Rebelo
Recife, Brazil — Marcelo Soares
July 2016

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## Part VII Information Design

# Part I
# Virtual Reality Challenges for the Future of Design

# Virtual Reality Technology Applied in the Building Design Process: Considerations on Human Factors and Cognitive Processes

**Daniel Paes and Javier Irizarry**

**Abstract** This paper discusses the most relevant human factors and cognitive aspects associated to the use of three-dimensional virtual reality models within the conceptual design phase in the construction industry. It contributes to the knowledge on the designer's cognitive functioning throughout the creative thinking and decision-making in design, as well as in what extent VR technology helps in these cognitive processes, pointing out relevant aspects that must be considered in the development of new VR-based tools for conceptual design. At the end, this study presents a concise knowledge on the meaning, impacts and effectiveness of VR technology for the Building Construction domain. The mechanism of human cognition involved in the building design process and the role of VR technology in this context are presented and final considerations are made.

**Keywords** Virtual reality · Building design process · Cognition · Human factors · Knowledge representation

## 1 Introduction

The knowledge regarding the nature and behavior of information in the construction industry and how designers solve the "ill-defined" architectural problem (the cognitive aspects involved) can provide answers that could guide the development of best-suited and human-centered computational tools. Goel et al. [1] suggest four key features for those cutting-edge technologies: (a) focus on the conceptual design and on the creativity of the designer; (b) emphasis on the creative process; (c) support to collaborative project and (d) supported by the cognitive science.

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Several studies have explored methods and tools for supporting creativity throughout the design development, especially for the analysis of conceptual solutions and flow of the designer's cognitive process. Studies on the language adopted in the conception process can also help in establishing a more appropriate information representation for the design phase. The graphical representation may be the most suitable in terms of flexibility, conciseness and ease of fault detection. The trend is the development of tools that offer the possibility of more insights in the process of generating ideas [2].

In order to develop the next generation of computational tools, it is also essential to adopt a user-centered approach. Information systems have been conceived and developed from a perspective focused on technology, where users and their demands are not properly considered, thus increasing the chances of those systems to become obsolete, not adopted or even ineffective. Techniques based on this approach seek to represent knowledge in a way that can be understood, stored, organized and managed by computers. On the other hand, in an user-centered approach, the main issue to be addressed is the applicability and usability of the technology considering the real demands of the human component and the way through which he/she seeks and uses information. For this reason, the techniques of representation centered on the human are able to optimize the creativity of the designer. The challenge lies on the creation and adoption of efficient representations for both cases simultaneously [2–4].

This study is built upon the dynamic relationship among human factors, cognitive aspects and knowledge representation, as illustrated in Fig. 1. Based on the understanding of the simultaneous functioning of those concepts, this paper discusses the role, impacts and effectiveness of virtual reality models within the building construction industry.

## 2 Cognitive Processes in Building Design

According to Florio [5], studies on cognition arose alongside the development of computers and artificial intelligence. The term *cognition* was often understood as *computing*, i.e., as the act of processing data and information. The author defines cognition as "the process or aptitude to acquire knowledge, which involves processing information through perception and reasoning."

Human cognition is related to the paths through which humans acquire knowledge, accumulate experiences and develop skills, from their interaction with the surroundings. In this cognitive process, humans use symbolic language for the representation of the reality which is, therefore, inevitably metaphorical, built on assumptions that prevent them to know it precisely. In a dynamic process, the human being perceives, processes and creates a mental representation of his/her own and particular reality [6]. In turn, the mental representation can be externalized, stored and communicated to others through several different methods, including by computer processing.

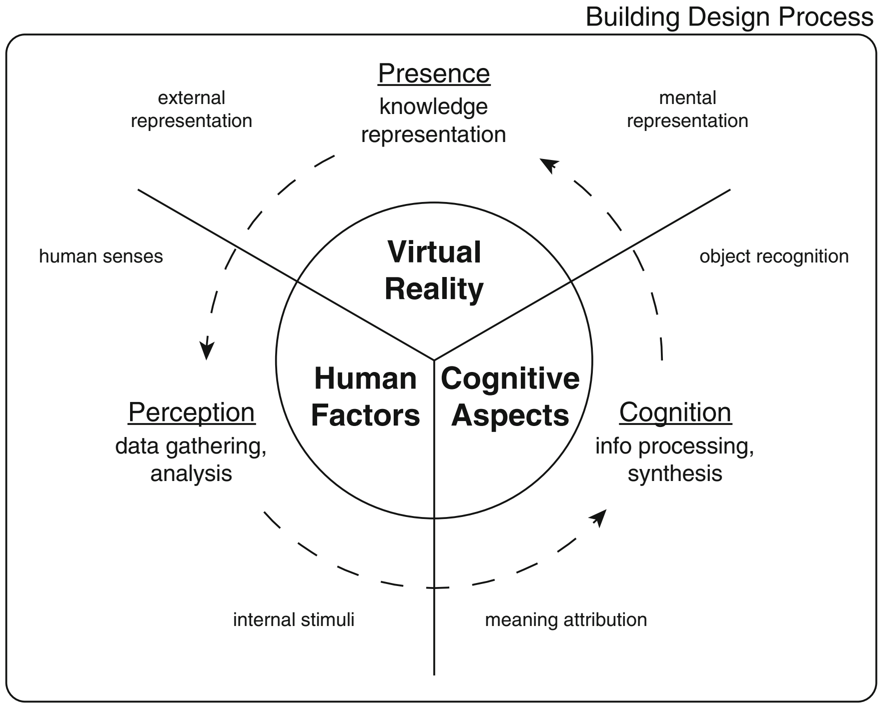


**Fig. 1** Relationship map among human factors, cognitive aspects and knowledge representation in the building design process

In the design process of a new building, a first designer starts the discovery process of an abstract object that occupies his mind. He/she assimilates this object by describing and representing it in his/her mind as a mental representation or externally, through drawings, verbal language or computational models. While in the form of a representation, other minds can assimilate and contribute to the knowledge about that object. To the extent that people receive, share and add new information, the object may change to a different one [3]. This is the collective creation of meaning, or the essence of the collaborative design process. At this moment, the abstract object does not “belong” to the person who started the process of its representation, but to all who may contribute with pieces of knowledge about it.

According to Chandrasegaran et al. [2], knowledge—as a resource—is not directly available in the design process environment, but is obtained by the interpretation of information deduced from the data analysis, in a dynamic and continuous process throughout the design. Thus, the design process can be considered as a knowledge production process, in which the need for information arises when the subject misses some specific knowledge, upon the inability to give meaning to a particular problem. By seeking additional information, humans are actually trying to change their situation of lack of knowledge [3]. Uncertainty is the driving force responsible for inducing research and promoting findings towards a consolidated knowledge, which would be the final design in the construction domain [5].

The design process is an investigative process of knowledge acquisition or production on a given building, very similar to the scientific research practice. The designer learns about the problem, the abstract object under investigation—or the desired building—to the extent that he/she attempts to solve it (to conceive it), not necessarily through pre-established rules or a methodology [7, 8].

Florio [5] states that the analogical reasoning by mental retrieving of previous knowledge is the most used strategy by proficient architects. Therefore, the design would be a dynamic adaptation process where prior knowledge is recovered and applied to a new project. However, whether the designer cannot rely on a previous knowledge—due to the lack of it—he/she would proceed through the trial and error method.

According to Schön [8], research in architecture would be a process of "reflection-in-action". The author states that designers would think about what they are doing at the same time they do. According to Florio [5], during this experimental process the designer "confirms or rejects each of the hypotheses," using graphical representations, models and prototypes that support the analysis of design solutions, the so-called "critical analysis" or "design review."

In the design review, human cognition is related to intellectual processes applied to representations or models of the desired building. A model is an abstraction of the reality, according to an eventual conception of it. It is the knowledge obtained from that reality. The model is not the representation of something, but the representation of what is known about this something (about a given concrete or abstract reality). The model can support communication, learning and analysis of relevant aspects of the context that it seeks to represent. It preserves and communicates a particular idea about the world, and can serve as a vehicle for reasoning, problem-solving and acquisition of new knowledge [5, 9]. It seems reasonable to apply this definition to all possible models that the architectural design may adopt.

Assuming that *to represent* means "the act of putting something in the place of", the representation can be considered the expression of thoughts derived from observations, using a specific language available in a given field of knowledge. In the building construction context, the representation "puts something in the place of" the designer's thought, derived from observations on the user's demands and other constraints. The model of a building is, therefore, a symbolic representation of the knowledge acquired or produced on a particular project. Sketches, maps, written notes, physical or virtual models are all different forms of design representations, external representations of the designer's ideas and knowledge on a given abstract object (in the intellectual level) [5, 9].

The conceptual design process is basically a process of knowledge production and representation about a given unprecedented building. It is important to notice that each project demands different or new knowledge, since constraints are never the same. Thus, it seams incoherent to think about automation in design (while a creative process), since it often demands unprecedented and creative solutions. It would be like automating research. Also, at the early stages of the design process the infinite range of possible solutions cannot be properly represented and communicated by two-dimensional architectural drawings. On the other hand, the use of virtual three-dimensional models facilitates the design understanding by all stakeholders, not being restricted only to those who know the symbols and codes of the two-dimensional representation, leading to better communication, supporting more collaborative tasks, and contributing to the formulation of more integrated solutions [10, 11].

## 3 Human Factors in Building Design

### *3.1 Perception*

Human senses are the interface mechanism of the individual with the surrounding reality and the interpretation of external stimuli captured by those senses results in the phenomenon of perception. In fact, perception is added by internal stimuli that also have influence on the subject's behavior in the process of perception. The subject reacts to the sensations that arise while interacting with that symbolic reality that he/she has built for him/herself. Somehow, the individual is actually stuck to his/her own metaphoric reality [6].

According to Rohrer [12], among the human senses, vision is the one with the highest power of information gathering, able to capture a large amount of information almost instantaneously. The image is the basis for human understanding: "human beings think and create in a graphical world." The author states that graphical animations use the ability of the human mind to process large sets of information, and are powerful tools in supporting the understanding of complex ideas.

However, the environment may provide more information than the individual is able to assimilate. The individual then divides this volume of information into smaller groups. Some of these groups are ignored; allowing the individual to focus on what is most interesting, performing an adaptation of the surroundings for him/herself, giving it meaning and significance. Also, the perception of some surroundings features such as size, distance and height is largely influenced by personal human characteristics such as cultural background [13]. According to Choo [3], to establish the relevance of external information is a subjective and situational task, driven by emotional circumstances.

In the extent that perception is selective and subject to personal human factors (physiological and psychological), human beings perceive reality in different ways. They can only assimilate what is noticeable on an absolute reality (the truth), more complex than he/she realizes. The individual perceives reality according to the universe of his/her particular thoughts, his/her intellectual background. The reality that he/she creates is restricted to this condition. His/her mind selects only few aspects from the surroundings, that are interesting in some level or that call him/her any attention, and then there are perception and awareness [6].

## 3.2 Awareness

To the extent that only some information captured from a given representation are relevant in a specific situation or context, the conceptual design process would benefit from the adoption of user-centered applications focused on improving the designer's situation awareness. According to Endsley [14], situation awareness is the process of realizing the surroundings in order to make decisions based on the assimilated information. It also means having access to relevant and sufficient information to make the right decision towards a predetermined goal. The author precisely defines situation awareness as "the perception of the elements in the environment within a volume of time and space, the comprehension of their meaning and the projection of their status in the near future."

Situation awareness takes place in three stages: (1) perception of the elements in the situation; (2) understanding the meanings of these elements (what they represent, the reason for their existence: attribution of significance to the acquired information) and (3) projection of the future status of these elements (through the tacit knowledge, previous experiences, assumptions or simulations). It is important to notice the strong resemblance between the stages of the situation awareness process and the nonlinear stages of the building design process. Both make use of analysis (data/demands collection), synthesis (generating solutions) and critical assessment (decision-making from the prevision of the consequences of proposed solutions). The situation awareness approach becomes interesting in contexts where information cannot be automatically generated or managed, such as in the design environment. When optimized, it can lead to improvements on the decision-making process in different contexts [5, 7, 8, 14].

Within the building design process, the *situation* would be the "ill-defined" problem, the intended space [7, 8]. At first, designers need to realize and analyze elements of this situation, which can derive from several aspects such as locational, organizational, institutional, philosophical, conceptual, economical, operational and functional.

The next step would be to understand the situation (not just realize it), the problem itself. It consists on synthetizing this information in a superficial and yet incipient idea about the space (first solutions), further than just having the conscience of the existence of those constraints and towards the understanding of the significance of these elements in the light of the project goals. The understanding of the situation in this context means the synthesis of these elements in architectural form and function: the volume, the party, the typology, etc.

The third step, or the "projection of future state of the elements", consists in the ability to predict the future behavior of the proposed solutions. The need for forecasting future events is inherent to the process of experimentation (tentative-error) within the design development and is crucial to determine the suitability and relevance of the proposed solutions. Predicting the future state of the elements will guide the designer in his/her final decision on a particular solution (adequate or inadequate). It can only happen upon the understanding of the situation and on the problem representation (mental or concrete representation). The critical assessment (design review) fits into this context as a procedure to evaluate the impact of design solutions, upon the prediction of their future status in the project as a whole. It is performed after checking and understanding the problem (analysis and synthesis of elements) and with the use of the designer's tacit knowledge and/or knowledge produced through simulations [5, 7, 8, 14].

# 4 Knowledge Representation in Building Design

## *4.1 Representation Versus Reality*

The building construction process involves manipulating information between two different ontological levels, two distinct "realities", the abstract and the concrete levels. The abstract level is constituted by the designer's ideas (abstract objects) whereas physical objects constitute the concrete level, the materialization of those thoughts. The representation plays an important role in this process; intermediating and supporting the information flow, given that the concrete building is still made of information.

In order to understand how representation supports the information flow within those levels, it is important to discriminate between representation and reality. From a philosophical point of view, they belong to different universes. According to Alvarenga [9], the objects under the process of knowledge, i.e., the objects on which thoughts and concepts are built, on which statements are made, and for which a representation is created, are part of the field that philosophers call *ontology*: the universe of all existing beings, both concrete as abstract. Therefore, the building as an idea inside the designer's mind is an ontological existing object, although in the form of an abstract object. The pictured building is an abstract and real object in the intellectual level, the level of thought. The building becomes an ontological concrete object when real on the physical level. Unlike abstract objects, concrete objects have well defined contours.

Assuming that an ontological object exists and is real, even as abstract or pictured, one can say that a given building exists as an idea, in the intellectual level. However, the building as a virtual model is a representation through which it is possible to learn more about that abstract object it seeks to represent. The virtual model carries graphical information that can be easily assimilated by human beings through the sense of vision.

A book, a manual, a photo book, a DVD containing a movie file, a flash drive containing digital files, all documents and artifacts that carry knowledge are concrete ontological objects in themselves, as physical objects. However, the information that they carry regardless the format it is represented—a text, drawing or sound—is an epistemological object. The representation is part of the universe called *epistemology*, the field of philosophy that deals with understanding the processes of the knowledge phenomenon [9]. The object exists (in the human mind or in the physical world, the ontology universe), a person gets to know it through perception and then he/she represents it (the epistemology universe), consecutively. Representation is the expression of the result of the perception process, limited to what is possible to observe or imagine about that ontological object.

The mental representation arises from the manipulation of symbols and concepts stored in the designer's mind that are used at certain moments to give meaning to the scene [5]. Faced with a new environment, the human being seeks to assimilate it by trying to give it some meaning and creating a mental representation of that world. Thus, human beings learn from the reasoning on representations only (mental or graphical), and never from the observation of the absolute reality (the truth). Again, the reality that humans experience—the environment that surrounds them—is actually a representation [6]. We learn, therefore, from the observation of what we call reality, which, in fact, is nothing but a mental model.

To represent an abstract object is not a trivial task. Given that it does not have recognizable boundaries, the adoption of representation tools that could approximate the experience of realizing an abstract object to the experience of perception of a similar concrete object could lead to promising results.

## *4.2 Virtual Reality*

An efficient computational tool for the design process must incorporate the ability to not only collect, store, retrieve and distribute knowledge, but to represent it properly, so that it can serve as a valuable resource [2]. Without proper representation, the knowledge becomes hard to understand or even useless. In the building construction context, the way knowledge is represented can have a significant effect on the design understanding and quality. Adequate representation would require less translation effort, allowing the design to be easily shared and assimilated. A method for optimizing the representation of information is through the use of virtual prototypes, which can also be displayed within Immersive Environments, where the user can actually walk through the information. Virtual reality offers the highest representation quality from the user's perspective, contributing to the understanding of complex four-dimensional data [11, 15, 16].

Chandrasegaran et al. [2] found the prevalence of certain types of representation in each stage of the engineering design. In the early stages, knowledge representation is predominantly pictorial (two-dimensional static images), whereas virtual representation appears most frequently in the central and final phases, where most of the decisions on the project have already been made [10]. The challenge relies on bringing the knowledge usually produced and represented in the central or final stages through VR-based technologies to the early stages of the design process, i.e., to employ virtual reality in the conceptual design [2].

According to Steuer [17], the concept of virtual reality is often reduced to the idea of a set of equipment, devices and hardware, not considering the "experimental nature" of this technology. The author strategically defines virtual reality as a particular type of human experience enabled by the feeling or sense of presence, allowing the distinction between existing virtual reality systems, not taking by reference the technological apparatus only. According to the author, *presence* is the human feeling of being present in a given environment upon the perception of it. When the perception is mediated by a communication technology, presence becomes *telepresence*. According to this definition, virtual reality consists in any telepresence experience. It is important to notice the strong resemblance between that definition of presence and the situation awareness approach discussed before. The more the user realizes a given situation and develops "situation awareness", the greater his/her sense of presence, in a cyclical process.

The use of three-dimensional virtual models contributes to a better understanding of the spatial configuration of a given designed space, as well as to support decision-making based on the visual assessment of design solutions [10]. According to Gifford [13], "the spatial cognition is a thinking act, through which the individual estimates distances, recognizes environments and gives meaning to the spaces with which he/she interacts." Therefore, the adoption of representations for the design process that are closer to the "existential-spatial" experience is of fundamental importance, so that spaces are designed to match technical, functional, symbolic and end-user's demands [11, 15, 16, 18, 19].

Virtual modeling can bring the benefits of physical mock-ups—commonly built at ultimate design stages—to the early stages of design and planning, where improvements are possible at less cost. Adequacy of space, safety issues and volumes can all be assessed using the VR mock-up [18]. In turn, the major benefits provided by Immersive VR Environments compared to traditional non-immersive VR are the interactivity—changes in the viewing according to the user's movement, for instance—and depth perception from the stereoscopic animation [11, 19]. Dunston et al. [18] performed a qualitative comparison between the desktop and the immersive displays and concluded that the immersive system provides a "better sense of spatial awareness." Paes and Arantes [11] conducted an extensive study regarding the perception obtained from each of those two VR platforms (projection-based immersive VR and non-immersive VR). The authors concluded that the projection-based immersive environment significantly enhances the understanding of the three-dimensional representation, especially for construction industry practitioners.

Faas et al. [20] conducted an experiment where the sense of presence was employed as a metric for assessing the designer's level of engagement and involvement in the design task. The authors also investigated whether the level of engagement in the design activity is related to better performance and better designs. The study concluded that the intensity of the sense of presence is a performance indicator in the design practice, by realizing a directly proportional relation between level of engagement and project's quality. In summary, high levels of presence lead to great involvement and thus, to better designs. Whenever the designer feels "present" and deeply engaged in the activity, better solutions will emerge. Therefore, whether a given virtual reality system offers a higher level of presence, it becomes capable of improving designer's performance in design review and critical analysis tasks, through improving spatial comprehension on the virtual model.

## 5 Discussion

The design process involves ultimately the act of understanding an abstract and unprecedented architectural object. However, one issue that comes up in this context is how to represent something abstract, with no precedent, thus hard to recognize. In order to accomplish that, it is assumed that the designer reports to the knowledge on similar objects to that abstract one he/she seeks to represent (whose contours are still unclear in his/her mind), attaching pieces of knowledge—or concepts—to the abstract object in order to make it recognizable and put it inside the realm of concrete things. The building representation is, therefore, a combination of concepts and knowledge into an architectural shape. The design is a representation process of what can be known about a given abstract object, assigning concepts to it in order to make it meaningful. Thus, the designed building is knowledge in itself—a set of concepts—and the process of designing the building is a knowledge production process.

It seems reasonable to state that in the design process the building is not designed, but 'known'. This knowledge process involves steps with different levels of details: from the scope towards the executive design, for instance. The building already exists as an abstract object or idea: usually, one could state what it is, its function, etc. Throughout the design process these definitions are detailed through questions such as "What means, in architectural terms, a building to be a school? What does it must have to be considered a school?" The building design process is, therefore, the act to deepen the knowledge on this object, identifying, characterizing and representing its components.

The building as an idea is an abstract object on which it is impossible to use the senses in order to get to know and describe it. Its representation becomes fundamental so that the designer starts to receive the first stimuli from that. The virtual model consolidates what was known about the abstract object and serves as a support to further reasoning. Upon receiving stimuli from the representation, the designer can see and understand what is missing or what is not working, based on what he/she desires for that building. One can say that the representation has an practical formative aspect and not only of representing something: it serves as a tool to build and consolidate our "reality", everything we assume as real, an idea about the world (abstract or physical). In order to illustrate the mechanism of human cognition in the design process, Fig. 2 is presented below, where it is possible to identify the universes of philosophy, the position of the knowing subject, and the outcomes of visual perception and imagination.

While it does not exist physically, the building remains in the abstract level and the act of representing it will always involve a cognitive process on an abstract

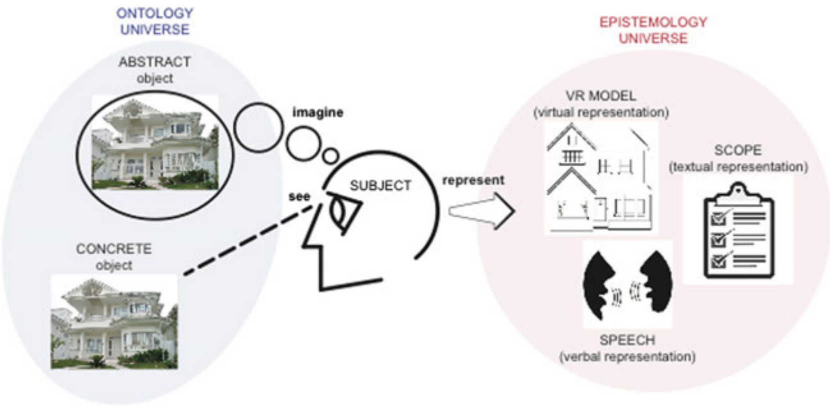


**Fig. 2** Mechanism of human cognition in the design process

object. Since it does not have well defined or identifiable boundaries, the representation of abstract objects is a challenging task. In fact, it is a process of assigning concepts and creating meaning for the recognition of what cannot be observed.

## 6 Conclusion

The quality of the building representation is not subject to the tools used to represent it or to the fidelity to representation standards only, but mainly to the similarity between the abstract object and its representation. The most relevant aspect of an effective tool for the design process seems to be its ability to reproduce and communicate—faithfully—the designer's idea.

In this context, virtual reality systems that are capable of promoting high levels of presence also offer the possibility of representing and communicating more accurately the elements that belong to the ontological universe (of what the designer can think of or see), although this representation will never be an exact reproduction of ontological objects, since it is subject to the limitations of human perception. The virtual model is always a representation in itself, an epistemological object. No matter how much computing power to simulate develops, the virtual representation will never be the ontological object, but always a representation of what the human being can know about the truth. However, it is exactly this power to resemble the world as we know it that makes the virtual reality technology a powerful tool to simulate and investigate the behavior of things according to our reality. Although, the results of possible simulations will also be limited to those inputs that did not correspond to the truth, they might be useful to predict the most relevant implications of a given design solution.

## 7 Future Work

Virtual reality systems have proven to be a promising technology for the building construction domain while offering a more suitable environment for the decision-making process in the design practice, where decisions of greater impact on costs, speed and quality of the projects are made and the ability to influence the total quality of construction is higher.

However, frequently, studies on virtual modeling and visualization in the building construction domain do not discuss whether and how the cognitive processes, when supported by virtual reality platforms, can lead to better designs. Furthermore, they often avoid discussing exactly whether and how immersive virtual reality offers better support to design practices compared to the conventional VR system, which would justify the adoption of immersive environments in the design process, rather than just checking parametric models through a conventional monitor. Finally, to assume that immersive environments can always reproduce or simulate physical world conditions with such fidelity, and to conduct research on this assumption, may lead to misrepresented results.

In this context, the authors aim to conduct further research in order to investigate and demonstrate immersive virtual reality systems' applicability, benefits and deficiencies in terms of representation of the virtual space, compared to non-immersive VR environments. In this upcoming work, the sense of presence in the immersive environment should be investigated in terms of the user' spatial perception. It is expected that results indicate a better spatial perception with the use of the immersive environment, therefore, a higher level of presence. A more accurate spatial perception (and higher levels of presence) would imply in a better understanding on the 3D model, beyond the simple recognition of the three-dimensional shape towards the assimilation of dynamic and multidimensional information.

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# Rapid Integration and Evaluation of Functional HMI Components in a Virtual Reality Aircraft Cockpit

**Matthias Oberhauser, Daniel Dreyer, Thomas Convard and Sebastien Mamessier**

**Abstract** This research presents a Virtual Reality Flight Simulator (VRFS) for the rapid integration and evaluation of Human Machine Interface (HMI) prototypes in a functional aircraft cockpit environment. In contrast to engineering mock-ups or full flight simulators, the digital cockpit mock-up of the VRFS presented here has a major advantage—it can be adapted without time- and cost-intensive hardware conversions, which is ideal, particularly in the early stages of the design process. The virtual cockpit is also connected to a flight simulation. This means that not only ergonomic but also cognitive aspects of new HMI components can be evaluated. This leads to the main objective of the VRFS: Demonstrating novel systems alongside existing cockpit components while using realistic operational scenarios. Thus, the subject's feedback does not only include comments on the HMI but also on its functional interaction with the cockpit ecosystem. This paper shows the technical setup of the VRFS and demonstrates the integration and evaluation of an HMI component in a use case.

**Keywords** Virtual reality · Humane machine interface design · Flight simulation · Human factors evaluations · Robot operating system

## 1 Introduction

The modern flight deck is a sophisticated workplace that controls a complex system with no room for errors. Flight decks, crew communication and the underlying systems have evolved over the last decades, making flying one of the safest means of mass transportation. The introduction of new technologies and operational needs has led—and will continue to lead—to new cockpit components [1]. With the

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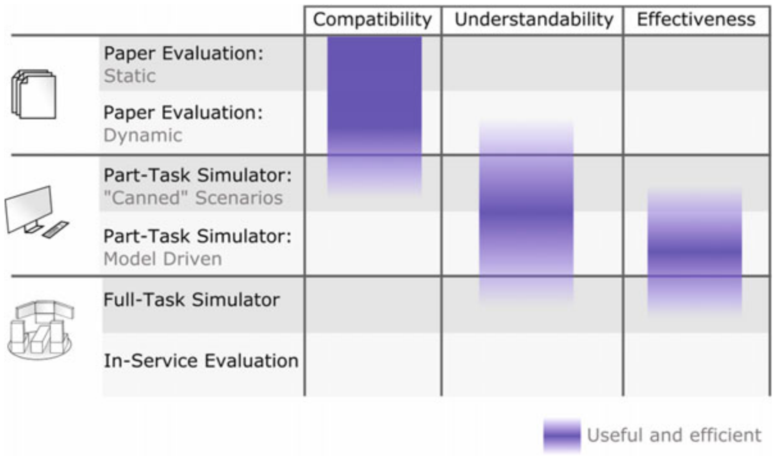


**Fig. 1** Levels of evaluation and the evaluation environments

introduction of these new components, existing problems in the Human Machine Interaction (HMI) can be solved. Yet, others might arise—especially with the interplay of existing components and procedures. In order to counter potential issues, Human Factors (HF) engineering has to play an important role in all design phases, including HF evaluations in all stages of the design process [2].

There are three different levels of evaluation: Compatibility—Can the system be used by a human? Understandability—Is it possible for a pilot to communicate with the system? And effectiveness—How does the pilot perform with the system? Abbott presents different means of evaluation environments ranging from paper based evaluations, part-task and full-task simulators to in-service-evaluations that have been time-tested and proven. As shown in Fig. 1, there is an environment for every level of evaluation that is both useful and efficient. Early in the design process, compatibility and understandability can be evaluated in a part task system. Later, however, the effectiveness should be evaluated in a full-task environment [1]. Some types of simulators deliver useful results for multiple levels of evaluation, yet, they are not efficient to use at this stage of the design process. For instance, an in-service evaluation gives useful insights on HMI components; but at this point, it is costly to implement necessary changes and therefore is not efficient.

This research leverages Virtual Reality (VR) for the evaluation of single systems in a holistic environment for all levels of evaluation. With the presented Virtual Reality Flight Simulator (VRFS), early research demonstrators as well as more advanced prototypes can be integrated and evaluated in a virtual cockpit. This paper describes interfaces for the integration of prototypes as well as the possibilities of Human Factors evaluations in an HMI development use case.

## 2 The Virtual Reality Flight Simulator

The Virtual Reality Flight Simulator consists of several modules. The core of the system is a six degrees of freedom optical tracking system that provides information on the head and hand position as well as the rotation. A virtual cockpit is rendered in a 3D engine with the camera rotation and position driven by the tracking system. For visualization of the virtual reality environment, a Head Mounted Display (HMD) is used. The hand and finger tracking data that is provided by the tracking system is used to position a 3D hand representation in the virtual world. Different types of interactions with the cockpit are possible with this finger tracking system.

Control elements can be fully virtual. Therefore, a separate module checks the finger positions for possible collision areas [3, 4]. If functional hardware elements are added to the environment, a so-called mixed reality is created, which enhances the usability of the system (see Fig. 2). Adding hardware elements is a trade-off between a very flexible, fully virtual system and a rather inflexible but highly usable system with various hardware parts [5].

The virtual environment is connected to a flight simulation with an aircraft system simulation, a flight physics simulation and an outside visual. This is important to create realistic scenarios for pilot evaluations. All components of the VRFS communicate using the Robot Operating System (ROS). This network layer offers the possibility to interconnect heterogeneous soft- and hardware components in an open source peer-to-peer network [6]. In the VRFS, the flight simulation component publishes the aircraft telemetry data, the tracking system publishes data about the movement of the pilot using the system, and the collision handler publishes interactions with the virtual cockpit. For post-analysis or development, the

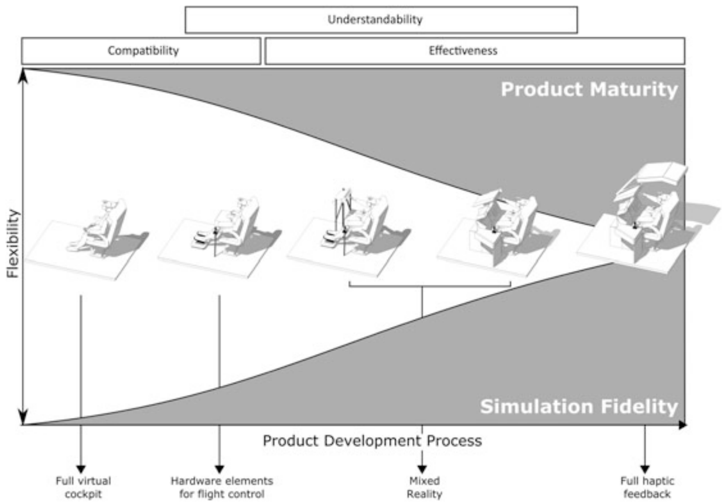


**Fig. 2** The VRFS in the product development process

complete communication between the different nodes can be saved in a time stamped data file, a so-called rosbag.

## 3 Prototype Integration

ROS offers a modular and distributed approach. Data, audio, and video streams can be shared between different applications, independent of the operating system or the programming framework [7]. Thus, almost every hard- and software component that is network capable can communicate with the ROS system, whether it is a PC-based system, a mobile application or a highly integrated micro-controller. This flexibility makes ROS an ideal candidate for interfacing with third party components. It is possible to add new system simulations, to provide external software with telemetry data, or to stream the content of an external display into the virtual cockpit. Either one or multiple of these options in combination can be used. If you take display prototypes for example, this results in different levels of integration: (a) a non-interactive playback of display content, (b) display content that is driven by telemetry data, or (c) a fully interactive display.

A non-interactive display prototype (a) can be a video or a static image of a proposed display. To integrate the content of such an external display, a screen capture software, which can be connected to the ROS network, is necessary. For the VRFS, Virtual Network Computing (VNC) is used to stream display content as it is a widely used standardized protocol. If the display prototype should be driven by the flight simulation data (b), the display prototype has to listen to messages provided by the ROS network. If an interactive feedback (e.g. a touch screen) or hardware buttons (e.g. line select keys) are needed, a bi-directional ROS connection has to be implemented and the display has to be placed at the exact same position as in the virtual mock-up. Figure 3 shows the interaction with a touch screen that has been integrated in the use case, which will be presented in the next section.

**Fig. 3** Interaction with hardware components in the VRFS

## 4 Use Case: Touch-Based Device

Here, a study about a touch screen device for aircraft system management will be presented as a use case to show the integration and usability of a prototype and its evaluation in the VRFS. The aim of the presented device in this use case is to simplify the task of managing aircraft systems by providing fewer, more general functions and by presenting these functions on a touch-based HMI in the head-down area. With this display, a pilot is able to control non-critical system management functions that usually are controlled in the overhead panel. Critical, irreversible functions are not part of this display due to safety considerations.

The touch screen device was implemented as a demonstrator on a mobile tablet device. The compatibility and the understandability of the device were tested in a part-task evaluation with test pilots. Based on the feedback gathered here, the prototype was further enhanced and integrated into the VRFS. It is accompanied by an overhead panel that offers access to irreversible functions that are not suitable for a touch screen device. Only with the combination of the touch screen device and the overhead panel, it is possible to create a realistic scenario. Hence, a part-task simulator is not sufficient to evaluate the effectiveness of the system integrated in the cockpit.

The prototype is implemented using web technologies (HTML 5 and the Jquery mobile framework), which can easily be connected to the ROS network. The different elements in the display, i.e. button states or system states, are driven by telemetry data from the flight simulation as shown in Fig. 4. User inputs on the other hand are translated into ROS commands and subsequently processed by the flight simulation. By placing the display at the exact same position as in the virtual cockpit, a mixed reality is created. Therefore, the pilot is able to use the touch screen in the virtual environment as shown in Fig. 3.

To expose the pilot to a high workload situation, a multi-system failure was chosen as a scenario: An electrical failure is followed by a fuel leak. The pilot has to deal with the electrical failure, identify and stop the fuel leak, and reroute the flight. To rule out confounding factors that stem from the virtual environment, a comparative study was conducted [8]. Thus, the scenario was completed once with a classic system management approach with an overhead panel and once with the novel touchscreen.

For evaluating the effectiveness of the novel system management approach, objective and subjective HF methods have been used. By means of the tracking system, the head and hand movements were analyzed as shown in Fig. 5. The time, the pilot looked at the overhead panel, and the time, the pilot needed to interact in the overhead area, were measured. From these two parameters, the relative physical workload can be derived. As the fuel leak scenario is a time critical event, analyzing and comparing task completion times led to a comparison of the performance of the task. All quantitative measures were automatically calculated by a script based on the data in the recorded rosbags.

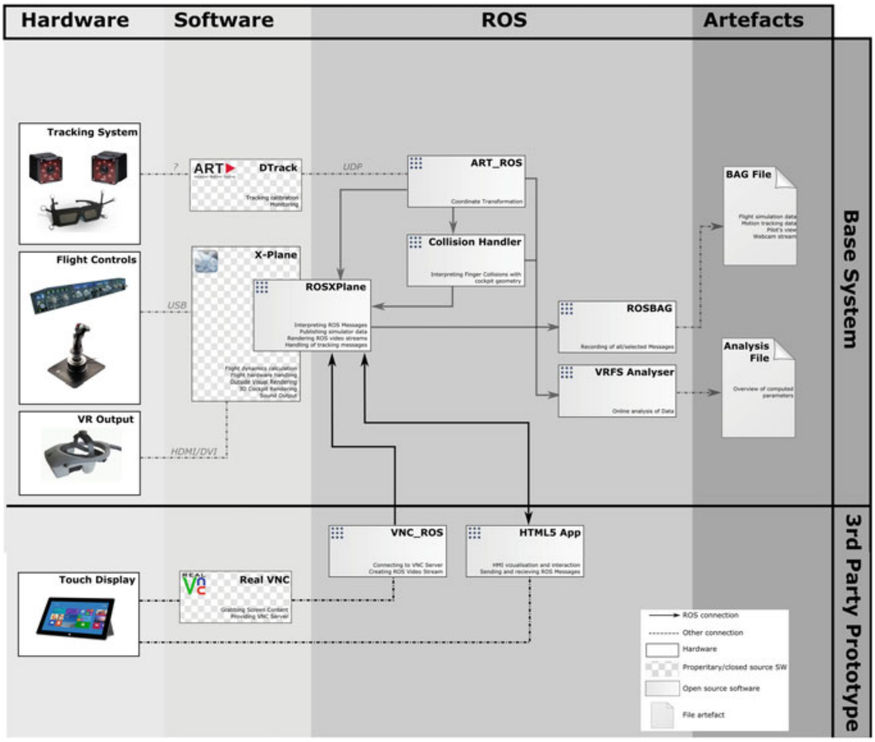


**Fig. 4** The architecture of the Virtual Reality Flight Simulator


**Fig. 5** Visualization of the recorded hand tracking data

These objective analyses were accompanied by subjective questionnaires to quantify workload and situation awareness, that is the NASA Task Load Index (NASA-TLX) and the Situation Awareness Rating Technique (SART) [9, 10]. These questionnaires were handed to the pilots after each scenario.

## 5 Discussion and Conclusion

This paper presents a Virtual Reality Flight Simulation environment for the integration and evaluation of HMI components. A use case is presented to show the integration and usability of a prototype as well as its evaluation in the virtual environment.

Today, in the cockpit development process, different types of evaluation environments are used depending on the level of evaluation and the development phase of the components, i.e. the technology readiness level. Due to cost and time constraints, the evaluation environments in the early phases of the design process are part-task simulators or even paper-based demonstrations. These environments are important for the in-depth evaluation of single system prototypes. Only later in the process, these prototypes will be integrated into a full-task simulator or are prepared for in-flight testing. At this point, ergonomic and cognitive aspects in the interplay with the existing cockpit ecosystem can be evaluated. The VRFS offers the advantage of a holistic full-task view on a prototype already in earlier stages of the design process. Paper concepts can be integrated as non-functional prototypes for compatibility or ergonomic assessments. Later, a functional virtual prototype or even a hardware prototype can be integrated and evaluated in a full scenario to get information on the understandability and effectiveness of the new system.

The goal of the VRFS is not to replace the current design and evaluation process of cockpit components but to supplement it with the possibility to integrate and evaluate components in a flexible, affordable and holistic cockpit environment in all stages of the design process. The presented use case shows the potential of part-task evaluations followed by the rapid integration and evaluation into the VRFS.

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# Virtual Reality to Study Job Interview Anxiety: Evaluation of Virtual Environments

**Tânia Borges, Elisângela Vilar, Paulo Noriega, Sara Ramos and Francisco Rebelo**

**Abstract** Empirical evidence has verified that anxiety is an inherent part of the interview process, and in today's stressful work environment it also has the potential of interfering with the ultimate goal of the interview: to recruit the most suitable person for the job and organizational fit. The objective of this study was to validate three virtual environments: (i) a business waiting room; (ii) an office with the presence of plants and a window view of nature (nature-like surroundings); and (iii) an office without nature elements. Hence, this study aims to validate the experimental and neutral virtual environments that will be used for further studies. A between-subject design was considered, and 66 university students participated voluntarily. Results evidenced the waiting room received unanimous and neutral ratings among conditions. The office with nature-like surroundings was more positively rated comparatively to the office without such surroundings.

**Keywords** Job interview anxiety · Virtual reality · Virtual environments · Validation · Interior design

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# 1 Introduction

Empirical evidence shows that in new and ambiguous social situations, observers' judgments and perceptions likely rely on environmental material objects [1]. Thus, in job interviews where the candidate has no control over the social interaction, nor does he know the inside of the company's built-in environment, we suggest candidates also rely greatly on the physical environment. Typical workplace objects (e.g., boardroom tables, briefcases, files and suits) increase cognitive accessibility, or prime, individuals into perceiving and behaving in a more competitive than collaborative manner [1]. Scholars identified that this behavior tended to occur more in contexts that were ambiguous and lacked explicit normative demands [1]. Given that the job interview is characteristically a social ambiguous context in an organizational setting, it is possible the candidate unconsciously relies on the physical environment. Meanwhile, other researches have greatly emphasized that environments with exposure to nature portray higher aesthetic responses and more positive feelings of well-being and comfort than environments without such elements [2, 3].

Inspired by previous findings, this study aims to validate the virtual scenarios with nature-like surroundings for further Virtual Reality (VR) job interview simulations. Considering the literature described previously, main hypothesis were that:

(i) A presentation of a waiting room prior the presentation of an office will have unanimous and neutral ratings across conditions.
(ii) An office with nature-like surroundings (window with a nature view and indoor foliage plants) will be more positively evaluated (i.e., have higher ratings) than an office without nature-like surroundings.

# 2 Methodology

A methodology based on participants' perceptions about a virtual office during a first job interview was used to validate the VR scenarios. In this way, a control condition (i.e. office without nature-like surroundings) and an experimental condition (i.e. office with nature-like surroundings) were considered. A waiting room was also evaluated, as this area should be considered as baseline area for data analysis for future studies using biofeedback systems.

## *2.1 Participants*

Sixty-six university students participated voluntarily. They were aged between 18 and 33 (M = 20.62, SD = 2.42) and had on average experienced 1.7 (SD = 2.51) job or internship interviews. The experimental condition (n = 33) was aged between 18 and 25 (M = 20.55, SD = 1.82) and had on average experienced 1.47 (SD = 1.88) job or internship interviews. The control condition (n = 33) was aged between 18 and 33 (M = 20.69; SD = 2.93) and had on average experienced 1.94 (SD = 3.94) job or internship interviews.

## 2.2 Virtual Environments

The Virtual Environment (VE) was developed based on architectural, psychological and computer engineering understandings that outlined the subsequent requirements for the VE development. The defined VEs would:

- Represent the context of an organization;
- Consider one context where the participant first waits to be called for an interview and then moves context for the latter event;
- Only one level (ground level);
- One aperture for the office;
- Existence of closed rooms;
- Uniform light/shadow effects for the experimental conditions that considered artificial lighting;
- Create and uniform light/shadow effects for the experimental conditions that considered sunlight;
- Insert decorative elements to increase depth perspective, such as ceiling moldings, and baseboards, as well as more functional characteristics (e.g., computers, files, meeting tables, sofas);
- Avoid extra environmental cues, such as, non-identifiable/visible textures on walls, floors or furniture; these would be replaced with solid colors;
- Consider a semi-controlled navigation approach—create strategies to avoid backtracking, i.e., closing door after entrance in office; and,
- Maintain the same travelled distance for all sections from the starting point (when the simulation begins) to the destination point (interviewer's desk).

The development of the VEs was performed in three phases. First, the base structure of the VEs were designed in 2D plans through the software Autodesk® AutoCAD 2009. The length and the width of the waiting room (6 m × 6 m) and office (8 m × 8 m), respectively, was maintained constant for all conditions. Next, these 2D plans were exported to SketchUp Make 2015 (Version 15.3.329). Through the latter program, the 3D environments were modeled. In this phase some elements such as ceiling moldings, baseboards and furniture were inserted to increase realism. The last phase led to an exportation of the 3D environments to the development platform Unity3D® where colors, decorations, illumination, the window view and plants were inserted. Images of the VEs developed are presented in Fig. 1.

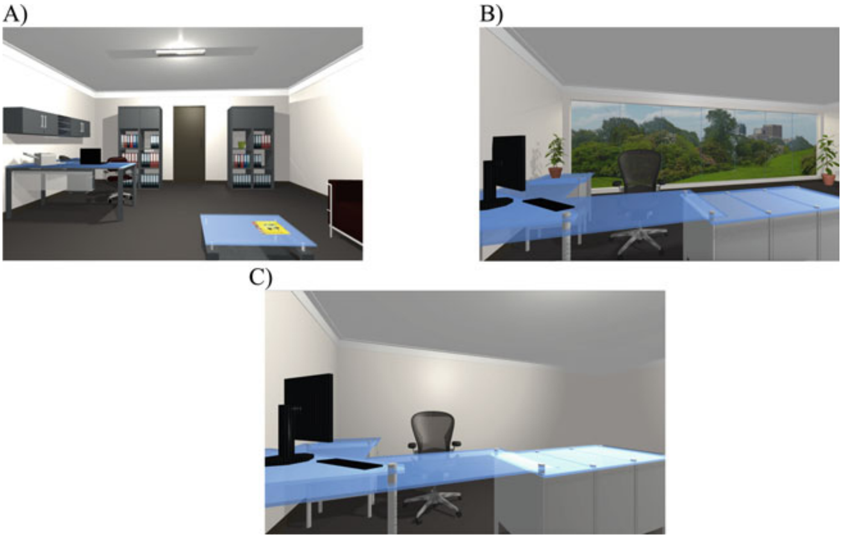


**Fig. 1** Image from the: **a** waiting room, **b** office with nature-like surroundings, and **c** office without nature-like surroundings

## 2.3 Materials

A MacBook Air Laptop (Intel® Core i5) with 4 GB RAM, a 13.3-in. display (1440 × 900), and an Intel HD Graphics 5000 1536 was used to present the images of the VEs from a first-person perspective (such as in Fig. 1).

## 2.4 Measures

The dependent variable of this study was the room assessment; thus participants reported their perceptions of the VEs against 16 polar opposite pairs of terms, using a Semantic Differential Scale [4]. The pairs of terms were translated and based on similar environmental assessments that have been conducted in previous studies (e.g., boring…interesting) [5]. Each pair was scored from 1 to 5, with 1 being associated to a more negative characteristic and 5 to a more positive characteristic in the pair. The polarity order of each pair was randomized.

## 2.5 Experimental Design and Procedures

A between-subject design was used and two experimental conditions were created: the experimental condition consisted of viewing the waiting room and the office with nature-like surroundings whilst the control condition consisted of viewing the waiting room and the office without nature-like surroundings.

In the university study areas, participants were approached individually and asked to evaluate a VE for a future study. An informed consent form was initially signed and then participants were randomly distributed between conditions. Through a PowerPoint presentation, all participants were shown the static image of the waiting room (Fig. 1a). They were then asked to respond to the first page of the questionnaire. Once they had finished, a static image of the office was presented, either with nature-like surroundings (experimental condition) (Fig. 1b), or without nature-like surroundings (Fig. 1c) (control condition). Next, they were asked to answer the second page of the questionnaire. Note that the same 16 polar opposite pairs of terms were used for all VEs. After this, demographic information was solicited such as age, gender, occupation and also the number of job interviews experienced. A debriefing explaining the study's general aim was given in the end.

## 3 Results and Discussion

The results that will be presented are regarding waiting room and office ratings. Further interaction with gender and numbers of interviews will also be considered. All dependent variables (waiting room and office ratings) showed to be approximately normally distributed across conditions. All tests of significance were conducted with an alpha level of 0.05.

We hypothesized that the waiting room would receive an average neutral rating and that this score would be equal across conditions, indicating group equivalence. Average ratings of the waiting room in both experimental and control groups were approximately 3 signifying the physical space was considered neutral for the majority of participants ($M = 3.19$; $SD = .48$, and $M = 3.22$; $SD = .40$, for experimental and control condition, respectively). An independent samples t-test was performed for the waiting room that showed there was no difference in the average waiting room ratings among groups ($t$ (62,14) = .30, $p = .77$, $d = .07$). This indicated that across groups the waiting room was equally considered a neutral environment.

On the other hand, participants' average office ratings differed significantly. The experimental condition (i.e., nature-like surroundings) received a significantly higher average rating ($M = 3.68$, $SD = .31$) than the control condition ($M = 2.96$, $SD = .42$; $t$ (64) = −7.95, $p < .001$, $d = 1.95$) (see Fig. 2).

In order to understand which characteristics differed most between the offices, a one-way between-groups ANOVA was conducted for the 16 room characteristics. The office with a nature-like surrounding revealed significantly higher ratings than the control office in 10 of the 16 characteristics (Table 1). Thus, when nature-like surroundings (plants and a window view of nature) were present in the room, the office was associated to more positive characteristics than the control room. These positive characteristics were: 'interesting' ($F$ (1,63) = 57.93, $p < .001$, $d = 1.90$),

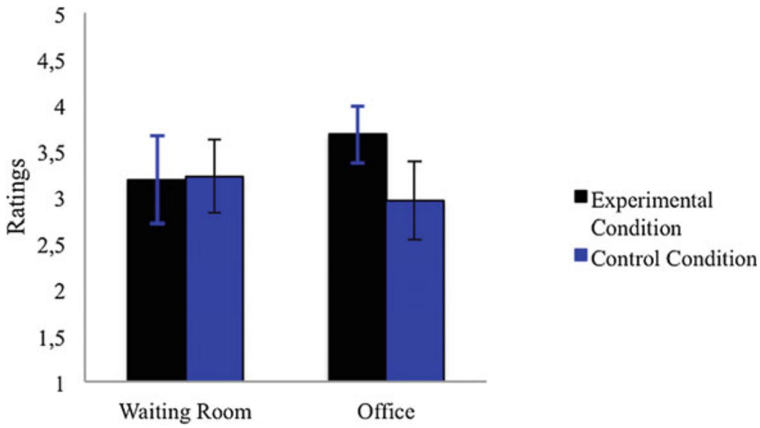


**Fig. 2** Average (standard deviations) VE ratings for the waiting room and offices with and without nature-like surroundings (experimental and control conditions), respectively. *Note* Average values are based on a scale of 1–5, with *1* associated with the more negative term in the pair and *5* associated with the more positive term in the pair of room characteristics

**Table 1** Average (standard deviation) ratings of the office without a nature-like surrounding (control condition) and with a nature-like surrounding (experimental condition)

| Room characteristic | Control<br>*M* (*SD*) | Experimental<br>*M* (*SD*) |
|---|---|---|
| Boring–interesting | 2.76 (1.00)** | 4.36 (.65)** |
| Sad–cheerful | 2.58 (.79)** | 4.18 (.64)** |
| Dull–colorful | 2.55 (.94)** | 4.00 (.75)** |
| Unfriendly–friendly | 3.00 (.98)** | 4.00 (.66)** |
| Hectic–calming | 3.55 (.75) NS | 3.33 (1.14) NS |
| Unpleasant–pleasant | 2.15 (.8)** | 3.24 (.66)** |
| Confined–spacious | 3.30 (1.2)* | 3.91 (.91)* |
| Ugly–attractive | 3.09 (.91)** | 4.30 (.68)** |
| Frightening–safe | 3.70 (.81) NS | 3.82 (.73) NS |
| Uncomfortable–comfortable | 3.33 (1.05) * | 3.88 (.89)* |
| Messy–neat | 4.52 (.62) NS | 4.52 (.67) NS |
| Plain–ornate | 1.36 (.60)** | 2.45 (1)** |
| Modest–sophisticated | 2.85 (1.25)** | 3.76 (.87)** |
| Unbelievable–believable | 3.70 (.92) NS | 3.85 (.566) NS |
| Formal–informal | 2.18 (.98) NS | 2.55 (1.01) NS |
| Old fashioned–modern | 2.82 (.77) NS | 3.15 (.57) NS |

*Note* Mean values are based on a scale of 1–5, with 1 most associated with the first term in the pair and 5 most associated with the second term in the pair
*NS* score is not significant, *score significant at $p < .05$, **score significant at $p < .001$

'cheerful' ($F$ (1,63) = 81.58, $p < .001$, $d = 2.23$), 'colorful' ($F$ (1,63) = 48.03, $p < .001$, $d = 1.71$), 'friendly' ($F$ (1,63) = 23.26, $p < .001$, $d = 1.20$), 'pleasant' ($F$ (1,63) = 34.59, $p < .001$, $d = 1.49$), 'spacious' ($F$ (1,63) = 4.28, $p < .05$, $d = .57$), 'attractive' ($F$ (1,63) = 36.2, $p < .001$, $d = 1.51$), 'comfortable' ($F$ (1,63) = 4.14, $p < .05$, $d = .57$), 'ornamented' ($F$ (1,63) = 27.3, $p < .001$, $d = 1.32$), and 'sophisticated' ($F$ (1,63) = 11.51, $p < .001$, $d = .85$). Other characteristics such as calming, secure, tidy, believable, informal, and modern did not reach significance ($p > .05$).

Further analysis was conducted considering interaction effects of gender. Women rated the waiting room significantly lower than men ($M = 3.07$, $SD = .45$ for women and $M = 3.34$, $SD = .40$ for men; $F$ (1,62) = 6.56, $p = .01$, $\eta_p^2 = .10$). Regarding the office ratings, a multivariate between subjects ANOVA (MANOVA) did not show a main effect of gender ($F$ (1,62) = 2.07, $p = .16$, $\eta_p^2 = .03$) nor condition x gender interaction ($F$ (1,62) = 3.60, $p = .06$, $\eta_p^2 = .06$, respectively). Nevertheless, women did report on average lower ratings for the control office ($M = 2.81$, $SD = .45$) than men ($M = 3.10$, $SD = .34$) and higher ratings for the experimental (nature-like surroundings) office ($M = 3.70$, $SD = .36$) comparatively to men ($M = 3.66$, $SD = .26$). These results our hypothesis that despite inter-individual differences among gender, nature-like surroundings is perceived positively across humankind due to our innate connection with nature.

Regarding the number of interviews participants had experienced, participants who reported to have no prior experience rated the waiting room similarly to participants who had experienced one or two interviews. Across groups the waiting room received neutral ratings ($M = 3.22$, $SD = .48$, for zero number of interviews experienced, $M = 3.23$, $SD = .49$, for one or two number of interviews experienced). A MANOVA was conducted with the number of interviews experienced (0 or 1–2) and condition (experimental or control) as between-subject variables. Results showed no main effect of the number of interviews experienced ($F$ (1,46) = .001, $p = .98$, $\eta_p^2 < .001$). Additionally, participants also stated approximately equal ratings in the control office ($M = 2.97$, $SD = .40$, for zero number of interviews experienced, $M = 2.95$, $SD = .46$, for one or two number of interviews experienced) and in the experimental office ($M = 3.62$, $SD = .25$, $M = 3.73$, $SD = .41$; for zero number of interviews experienced and one or two number of interviews experienced, respectively). A main effect of the number of interviews experienced was not verified ($F$ (1,46) = .18, $p = .68$, $\eta_p^2 = .004$) nor an interaction effect of number of interviews x condition ($F$ (1,46) = .34, $p = .56$, $\eta_p^2 = .01$). Such findings suggest the number of interviews, i.e., the candidate's experience, does not affect how positively they evaluate an office with nature-like surroundings.

This study's aim was to evidence the positive impression nature-like surroundings produced and more specifically, the presence of foliage indoor plants and window with view of nature. We first hypothesized that the waiting room ratings would not differ between conditions. The general results evidenced a neutral average rating of the waiting room among conditions. The average ratings were approximately 3 indicating a neutral perception of the environment among groups. This result emphasizes the possibility of using this environment to begin a job interview simulation as it conveys an impartial common ground for all participants. We also hypothesized that the office with nature-like surroundings would be more positively rated than the office without these characteristics. Results confirmed our hypothesis as the office with nature-like surroundings was in fact more positively rated than the office without this surrounding. The nature-like surrounding office was characterized as specifically more interesting, cheerful, colorful, friendly, pleasant, spacious, attractive, comfortable, ornamented and sophisticated than the control office. The positive ratings received by the nature-like surrounding are consistent with the findings of other researchers who have shown a positive attitude towards rooms with plants [5–7]. In addition, this pilot study upkeeps our main hypotheses for the ongoing Main Study. Nature-like surroundings are perceived positively regardless of gender and number of interviews experienced.

Although not all the pairs of terms differed between conditions, there are possible reasons that could justify these results. Firstly, both offices lacked objects such as papers, folders and pens on the table. This could have led to rating the offices similarly in regards to the pair 'messy–neat'. Further, given the environment is in a business building it can be stereotypically assumed that every business: represents a certain form of formality (pair: formal–informal); do not convey feelings of physical threat (pair: frightening–safe); and, both have a medium level between 'modern and old-fashioned'. Reasons for not achieving statistical differences between hectic and calming could be due to the translation of the term hectic to the Portuguese language and lastly, the non-significant difference between the pair 'unbelievable–believable' demonstrates that both offices were equally realistic to the participants.

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# Development of a Virtual Environment for Safety Warnings Behavior Compliance Evaluation

**Ana Almeida, Francisco Rebelo and Paulo Noriega**

**Abstract** The effectiveness of safety warnings is measured by user's behavior compliance. Although compliance is an important component in determining the success of a warning, its study becomes difficult to be developed in a real situation, due to methodological, financial and ethical issues. Virtual Reality (VR) can be a solution to these limitations. VR has the advantage of offering realistic experiences that even the person not being physically present in the environment feels like being there. However, for this to happen, it is necessary to develop 3D environments and narratives involving participants as if they were real situations. Since the construction of realistic 3D environment and consistent narratives a challenge for researchers, this study aims to develop and evaluate a 3D environment with a narrative to safety warnings effectiveness studies. The first part (development of virtual environment/narrative) was done through meetings with the multidisciplinary team Ergonomics Laboratory. The aim was to define requirements for the narrative and the virtual environment design features. The second part (evaluation of the prototype), through pilot tests, results will be discussed.

**Keywords** Virtual environment · Safety warnings · Virtual reality

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## 1 Introduction

The purpose of a warning is to inform people at risk about hazards and promote a safe behavior. The effectiveness of a warning is defined by how it reaches the goal of bringing the user to act safely [1]. It could be explained by the three-stage model (Fig. 1) suggested by Laughery [2]. In the first stage the warning should be seen, then read and understood and finally modify receiver's behavior to lead him/her to appropriate decisions. Thus, the ultimate criterion to say that a warning is effective is when it reaches the last stage and occurs compliance behavior [3].

We can find in literature studies related to signs and safety warning compliance [3–5], but few studies have evaluated the compliance at a high cognitive workload situation. Although compliance is an important component in determining the success of a warning, this study becomes difficult to be developed in a real situation. For ethical and security issues, participants cannot be exposed to real risks, and on the other hand, events that can cause injuries are relatively rare and simulate these situations has time and effort involved [6, 7]. A solution to these limitations is the Virtual Reality (VR), "a way of transporting a person to a reality in which they are not physically present but seems like they are there." [8]. The VR has the advantage of offering realistic experiences that even the person not being physically present in the environment feels like being there.

However, it is a challenge for researchers to develop 3D environments and consistent narratives involving participants as if they were real situations.

A 3D environment corresponds to the characteristics of the simulator as objects, sound and light, entered into the environment, which can be experienced by participants through the sensory channels. A good interface simulates a highly realistic three-dimensional environment where the participant is encouraged to explore and interact with the space as if he/she was really into it.

The other important feature that should be taken into account to create an experience in VR effective is the narrative [9], stories that are described at the beginning of the experiment, in which participants live in first person.

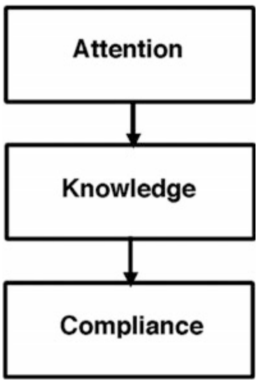



**Fig. 1** 3-Stage attention, knowledge and compliance (AKC) model [2]

In the present study we used an User Centred Design methodology to develop a virtual environment (VE) to study safety warning behavior compliance in high cognitive workload situation.

## 2 Method

It will be presented the methodological approach to the development of the 3D environment and narrative as well as the pilot study to assess the virtual environment which took place in two moments.

### *2.1 3D Environment and Narrative Development*

The multidisciplinary team (ergonomists, designers, psychologists) from Ergonomics Laboratory of the Lisbon University—Portugal, developed the concept of the VE and narrative, through brainstorming meetings. The aim was to define requirements for the narrative (history to be presented to the participants before interaction with the VE) and the three-dimensional VE design features.

The meetings discussion points were:

- The development of a narrative that involves the participant to have a good performance in the VE;
- The development of a VE that there were hazard as well as safety warnings and a set of tasks in which the participant had to perform associated with different levels of cognitive workload, in order to verify the compliance with the safety warnings in these situations.

### *2.2 Pilot Study—First Moment Experiment*

**Participants**. Eight university master students participated voluntarily in this study. However, two students quit the test because of sickness simulator and were not included in the sample. So, the sample was comprised of six participants. They were 3 male and 3 female and were aged between 22 and 45 years old (M = 25/ SD = 8.58).

**Apparatus.** Tasks were performed on a Desktop Station with an Intel® Core™i7-4790K CPU processor, 8 GB, NVIDIA GeForce GTX 980 video card. Virtual environment interaction was performed using a gamepad, Head Mounted Display (HMD), model DK, OCULUS (OLED display, resolution 960 × 1080 per eye, 100° field of view) and wireless PHILIPS earphones, model SHC5102/10.

**Measurements.** One of the objectives of this study was to evaluate the participant's behavior when faced with a safety warning in low and high cognitive workload situations. This variable was measured by participant behavior observation during the simulation, if he/she had a safety warning compliance behavior. The other objective was to evaluate the 3D environment for studies of the above mentioned nature. For this, some questionnaires translated to portuguese by Reis et al. [10] and adapted for this study were used. These questionnaires sought to asses participants subjective perceptions about their interaction with the virtual environment:

*Simulator Sickness Questionnaire (SSQ).* To measure whether there was some kind of discomfort or sickness during the simulation, the participant should rank 16 symptoms on a 4-point scale, where 0 meant "None" and 3 "Severe".
*Presence Questionnaire (PQ).* This questionnaire aims to evaluate the quality of interaction with the 3D environment through the classification of features like quality of sensory experience, distraction factors, degree of realism, sense of time.
*Overall Usability Questionnaire (OUQ).* The participant should evaluate the environment through the classification of the study context consistency with the proposed environment.
*Hazard Perception Questionnaire (HPQ).* This questionnaire aims to assess the perception of the participant of the existence of any hazard in that situation and how classified it in the sense of risk, probability, severity as well as their behavior.
*Safety Warning Perception Questionnaire (SWPQ).* The purpose of this questionnaire was to determine if the participant had seen and read the safety warning.

**Procedure**. The experimental session was divided into 3 parts: (1) training session; (2) VR simulation session and (3) response to a questionnaire. The average total time was 30 min. Depois de explicado o objetivo do experiment, era pedido ao participante para assinar o termo de consentimento e preencher o questionário demográfico. Depois disso era-lhe apresentado os equipamentos de interação a serem utilizados e dava-se início a sessão de treino. Nesta sessão o participante explorava um ambiente onde deveria percorrer salas e corredores e lhe era solicitado ler os placares que encontravam (para certificar que eram capazes de ler os avisos do ambiente da sessão experimental). Quando o participante se declarava apto, pedia-se para o mesmo ler a narrativa contextual, e então dava-se início ao sessão experimental. After the experimental session, participants were asked to fill out the questionnaires acima citados.

## 2.3 Pilot Study—Second Moment Experiment

**Participants**. Four university students participated voluntarily in this study. They were 1 male and 3 female and were aged between 18 and 43 years old (M = 26/ SD = 11.52).

**Apparatus, Measurements and Procedure**. Tasks were performed on the same apparatus as First Stage Experiment and measures and procedure were the same as First Stage Experiment

## 3 Results and Discussion

### *3.1 3D Environment and Narrative Development*

It was decided that the experiment would take place in a warehouse where the participant perform searching tasks and would be exposed to risk situations.

A warehouse is a commercial building used by companies for storage of goods and raw materials. Activities in a warehouse generally include goods loading and unloading, where you can easily identify several risks that can cause great damage. Some risks to which workers are exposed include: (1) Fall of goods, collapse of structures; (2) Vehicles movement on the environment; (3) Electrical hazards; (4) Adverse thermal environments; (5) Hazardous substances handling; (6) Fall on same level [11–16]

The narrative was developed from the characteristics of the defined environment. The participant would receive instructions to perform inventory control tasks and while performing these tasks would be faced to hazard situations with warnings.

Imagine you have been unemployed for 6 months and are having difficulty to find a job opportunity. Your major concern is that your family depends on you because their parents are also unemployed. You know, it is very difficult to find a job in the current job market, at their age. A friend, knowing your situation, got a job interview for you in a warehouse of a distributor of drugs. As it is a kind of work that is within your reach, because only requires that you would be effective in replacement tasks and medicines stock counting, it is a good opportunity for you. Also, if you get this job you can earn a good salary. Today you are called to do a test to see if you are eligible to work in the warehouse. Your capacity to respond to requests that are to be given and in particular your performance, it will be essential to achieve this work; and the same tasks that were to locate the requested boxes and answer personal questions (name, date of birth), as low cognitive workload condition and make mathematical calculation, as high cognitive workload condition. Our focus was on the evaluating the decision making behavior individuals assumed when in front of a safety warning when in low and high cognitive workload.

### *3.2 First Moment Experiment Results*

The data show that about 80 % of participants had the compliance behavior with the warning in the two situations of low and high cognitive workload. Although a

**Fig. 2** Simulator sickness questionnaire

participant declared have not seen the warning in low cognitive workload situation, he/she had a consonant behavior. It is supposed that the high compliance rate has justified because they were students who had in his curriculum a course on safety and health at work.

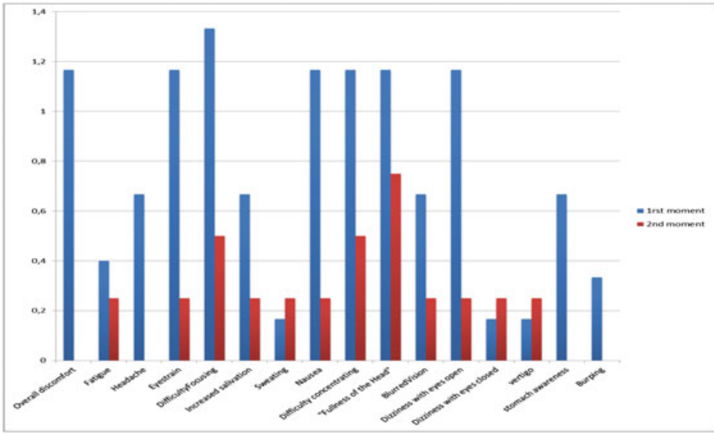
Regarding the SSQ (Fig. 2), the most common symptoms were: difficulty concentrating and "fullness of the head" (70 %), then discomfort general and dizziness with eyes open (60 %) and thirdly, eyestrain, focusing difficulty, nausea and blurred vision (50 %). Some participants stated that they were feeling some sickness but did not want to leave the experience.

The PQ showed that the sensory quality of experience has been, in general, positive (M = 6/SD = 0.85) could be noted readability of information on the environment (M = 7/SD = 2.10), the auditory stimuli (M = 7/SD = 1.73) and the naturalness of the virtual agent's voice (M = 7/SD = 1.06), which made the participants feel "inside" of the virtual environment. Regarding interaction quality with the virtual world it was classified as quickly and easily (M = 5.5/SD = 0.75). About distraction factors, participants reported having little awareness of what was happening in the real world as "were" in the virtual world (M = 2/SD = 1.81). The devices interact with the virtual world were not considered distracting factors (F = 3.5/0.5 = SD), the same as the image quality (M = 3.5/ = SD). They said although the task has been given by a virtual agent does not mess up their entire performance (M = 3/SD = 2.11). The degree of realism ranked simulation as reasonably real (M = 5/SD = 1.57) and in a way stated that their behavior in the simulation have been consistent with their behavior in the real world (M = 5.5/SD = 1.29). Declared also be involved in the simulation to the point of lost track of time most of the time (M = 6/SD = 1.35). The degree of immersion can be classified as the high (M = 5.5/SD = 0.65) can highlight the feeling of having been physically in the environment (M = 6.5/SD = 1.62).

As regards the OUQ, aspects that stood out were the high degree of involvement in the simulation (M = 6/SD = 0.63) and the context of narrative consistency due to the simulation (M = 6/SD = 1.32).

The HP data and SWPQ related to Warehouse 2 (low cognitive workload condition) revealed that participants were fully aware of the existence of hazard in Warehouse 2 (M = 7.5/SD = 1.37), however classified as just dangerous the situation (M = 4/SD = 1.43). Regarding the probability of suffering an injury, classified as probable (M = 4/SD = 1.20) and that the severity of the injury would be between severe and very severe (M = 5/SD = 1.51), so they had caution in crossing the space (M = 6.5/SD = 1.90) and were between very and total control to avoid having a risk composed meant (M = 7/SD = 1.58). They declared also unfamiliar with this situation (M = 1.5/SD = 2.47). With regard to safety warning declared fully aware of its existence in the environment (F = 7.5/SD = 2.51), and that it has drawn much attention (M = 6/SD = 1.84) and were able to read many times (M = 6/SD = 3.27) but ranked only as visible (M = 4.5/SD = 1.76).

When related to Warehouse 4 (high cognitive workload condition), the participants were very aware of the existence of hazard in Warehouse 4 (M = 6.5/SD = 2.04), and classified as a somewhat dangerous situation (M = 3.5/SD = 2.15). Regarding the probability of suffering an injury, classified as probable (M = 4/SD = 2.0) and that the severity of the injury was severe (M = 4/SD = 1.54), had a lot of caution in crossing the space (M = 6.5/SD = 1.97) and had a lot of control to avoid having a risky behavior (M = 6/SD = 1.89). They classified the situation as familiar (M = 4/SD = 2.94). With regard to the safety warning, declared much aware of its existence in the environment (M = 6.5/SD = 1.65), and that it drew a lot of attention (M = 6/SD = 1.49) and were able to read many times (M = 6/SD = 2.91) and classified as very visible (M = 5.5/SD = 1.71).

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# Child-Persona: What I Think to What They Are

**Ana Claudia da Costa, Francisco Rebelo and Júlia Teles**

**Abstract** Personas are representations of archetypal users aimed at guiding developers during the designing process. Because users—especially children—cannot be easily accessed, Personas have the potential to gather information regarding characteristics of a wide variety of people. Knowing user's abilities and needs is very important for making decisions about the fun conceptual system and the concepts that players should learn. This study presents the steps in the creation of Child Personas (CP) that will be used for designing a political educational game for Brazilian students. The data collection technique used was a questionnaire applied to 674 students aged 9–15 living in different regions in Brazil. To analyze the data collected by survey we ran the Two Step Cluster Analysis that has automatically determined three different clusters. Based on it we have created three child-personas by giving them, name, age, grade, family configuration, school, hobbies, activities, and a narrative to contextualize their lives.

**Keywords** Child-persona · User-centered design · Quantitative method · Cluster analysis · Game design

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## 1 Introduction

Nowadays children can do almost everything they need and like supported by new technologies [1]. Nonetheless, many products are still designed without taking into account their needs and abilities. For almost 20 years user centered design methods stress that it is important to invest time and energy in understanding users of technology and in bringing them into the design process. Yet this has been difficult to do with children users.

Within user-centered design (UCD), many methods have been developed to know better their target population. One method that is widely used in this space is the use of personas [2, 3]. Personas are a type of user model or an archetypical representation of real and potential users which illustrates the individual's characteristics [4, 5].

An essential benefit of Personas is that they build empathy for real target users, helping design team to stop talking about the general "user" [6], thus reducing reliance on assumptions and on personal experiences [7].

Despite the fact the Druin and Solomon in 1996 pioneered the concept of having children as part of the design team, it was only recently that researchers began to work more substantively with children [8]. To some extent, this could be explained by the difficulties to access them or to access their feelings given that young children can have more difficulties to verbalize their thoughts [9].

Most of the paper and field reports describe the personas creation using qualitative methods such as ethnographic studies and user observations [10]. However, according to [11], qualitative methods have two important drawbacks: the large number of participants which may result in textual data growth and the high costs. Also important are: subjective assignment decisions, the need for experience in qualitative research training, cognitive limitations of humans, and considerable resource commitments.

This paper aims at showing a quantitative method for child-persona creation to be used on an online political educational game to be published on the *Plenarinho*, the Brazilian's Chamber of Deputies' website for kids (www.plenarinho.leg.br). Our target audience is formed of children aged 10–14 from all over the country. Our goal is to create a game where kids can have a real experience as a representative in ways that are meaningful. It is about helping them to see responsibilities, difficulties and challenges of being a representative in a democratic society.

We chose to design an online game to teach kids politics inspired by a recent research by [11], showing that the decreasing interest of young students in political issues can be fought with educational games. But to make them a powerful educational tool, we must find out what really amuses our users in order to develop a very fun and challenging game that engage them on our subject [12].

To know our users and their interests we developed a questionnaire applied to 702 Brazilian's students aged 9–15. This questionnaire, comprised of 18 questions, derives from a preliminary study carried out in Brasília, Brazil, with 73 students [13], and from where we mapped out the most important aspects to be addressed on this survey. The five dimensions of the questionnaire were: (i) lifestyle, based on what prescribes [14]; (ii) gamers' preferences, based on [15]; (iii) players' styles, based on [16]; (iv) demographic information; and (v) social concerning, which included one question related to their worries concerning Brazil; one asking about what kind of problem in their school they would solve first (personal interest, shared interests, community interest), and another one about a dilemma (to cut Amazonia's trees and feed people from a starving village or not to tear down the trees and let village people starves). These last three questions were based on our interest in knowing how they feel about subjects we'd like to explore during the political educational game.

We didn't include questions concerning socio-cognitive characteristics, because this knowledge can be found in specific literature, including generalizations based on Piaget's age-dependent stages and in Vygotskian social cognitive perspective.

In this paper we present a quantitative methodology, and the statistical approach to analyze its results in order to create child-personas.

## 2 Methodology

Our study has used a questionnaire with 19 closed-ended multiple choice-type questions, which addressed the five dimensions previously mentioned.

Participants were convenience sampled at schools from teachers already know by Plenarinho's team. Although this kind of sample can be criticized because its application is not random or typically representative, we tried to ensure that students from all Brazilian's regions, covering schools from different social economic classes and different sociocultural background were reached.

Eight teachers were invited to participate based on the criteria that they had been selected to take part on a face-to-face course about civic education at the Chamber of Deputies. Teachers were instructed to apply the questionnaires and to explain students its context. The questionnaires were sent to their schools and returned to us by mail.

In total we received 702 questionnaires, 55 were eliminated due to the fact that respondents were older then the target users. Final sample was composed of 674 questionnaires answered by 48.2 % boys, 41.7 % girls; 49.3 % studying in private schools, 49.1 % in public schools from the following Brazilian's regions: Center (51.6 %), North East (24.1 %), South East (19.8 %), South (2.5 %), North (2.2 %). The average age of students was 12.9 years with a standard deviation of 1.36.

The answers given by students were first registered into an Excel file, where we converted string variables into numerical variables. After, they were imported into SPSS program where we began to treat data by running frequency tables for each variable, splitting the sample by gender and type of school (public and private schools). The analysis by type of school allowed us to verify if there were discrepancies among students from different social economic classes. Based on the frequency tables we could identify 43 variables that differentiated participants which were used to perform the cluster analysis.

To analyze the data collected by the above-mentioned survey we ran the Two Step Cluster Analysis tool of IBM SPSS Statistics, version 22 [17]. Cluster Analysis is a technique aimed at identifying clusters of users by addressing variables that differentiate users, and based on that, at setting up homogenous groups of users [11]. This method can handle categorical data and automatically determine the best number of clusters. The results of cluster analysis can contribute to find representative groups of users [10] by distinguishing prevailing interests and needs of each one of them which suggests us the personas' attributes. To make them more realistic, personas must be presented in a narrative which describes them in a way that articulates all those information.

## 3 Results and Discussion

Table 1 presents results of questions, which have had homogeneous results after running frequency table. They are presented here because they were not taken into account during cluster analysis since we were interested in questions that gave rise to discrepant answers.

Looking at this frequency table, what caught our attention was the fact that most students would let the village starves but would not allow tearing down Amazonian's trees. We wondered if this is a result of media "saving the environment" discourse. Later we will see another answer that can be dictated by media influence over kids.

Results concerning family configuration, presented in Table 2, reveals that most of them lives with mother, father and sisters and/or brothers. We did not include this

**Table 1** List of questions and the corresponding most frequent answer

| Question | Most frequent answer | % |
|---|---|---|
| 1. Concerns about school | Common problems | 59 |
| 2. Complying new rules | Giving rewards | 57 |
| 3. Where to play with friends | Outdoors | 57.3 |
| 4. Dilemma | Not tearing down the trees to feed starving village | 75.1 |

**Table 2** Results for family configuration

| Family configuration | % |
|---|---|
| Father, mother, brothers/sisters | 50.7 |
| Father, mother | 12.3 |
| Mother | 10.1 |
| Mother, brothers, sisters | 9.3 |

variable in cluster analysis, but we took it into account when creating personas narrative.

After selecting 42 variables we ran the two-steps cluster analysis. As presented in Table 3, this analysis has automatically determined 3 different clusters that were used as reference to form the persona narratives.

We should highlight some results showed in Table 3, especially those related to game preference and goals when playing game.

Cluster 1, with 94.6 % of boys, showed interest in playing first person shooter games. This is consistent with studies [18, 19], which suggests that boys are most attuned to violent games. If we use Bartle's well-known model for grouping player personalities, they could be classified as killers: type of player who like to impose drama over other players in virtual worlds.

**Table 3** Main variables and the prevalent categories of each cluster

| Variables | Cluster 1 | Cluster 2 | Cluster 3 |
|---|---|---|---|
| Gender | Boy (96.4 %) | Girl (72.4 %) | Girl (69.1 %) |
| School type | Private (60.9 %) | Private (81.2 %) | Public (93.9 %) |
| Grade | 8 (42.2 %) | 8 (30.4 %) | 7 (37 %) |
| Goals when playing | To be on the top of the ranking (31.8 %) | To find out what no one else knows (42 %) | To find out what no one else knows (39.4 %)<br>To kill the enemy (25 %) |
| Favorite type of TV program | Movies (47.4 %) | Series (42 %) | Soap operas (56.4 %) |
| Favorite type of online game | First person shooter (43.2 %) | Adventure (29.8 %)<br>Simulation (24.3 %) | Adventure (45.5 %) |
| Favorite type of movie | Action (30.7 %) | Action (29.8 %) | Terror (30.9 %) |
| Favorite type of game | Physical skills street games (89.6 %) | Physical skills street games (42.8 %)<br>Intellectual games (27.1 %) | Playing physical skills street games (68.5 %) |
| Time online/day | More than 3 h (42.7 %) | More than 3 h (45.3 %) | Less than 1 h (32.1 %) |
| Favorite game device | Computer/PC (43.2 %) | Cell phone (40.3 %) | Cell phone (49.7 %) |
| Routine out of school | Plays on computer at home (38.5 %) | Plays on computer at home (40.3 %) | Helps cleaning her house (51.5 %)<br>Watches TV (36.1 %) |
| Concerns about Brazil | Health (37.5 %) | Health (49.9 %) | Health (54.5 %)<br>Safety (27.5 %) |

We can also identify some similarities among clusters. Clusters 2 and 3, both composed mainly by girls, are interested, when playing online games, in finding out what no one else knows about it, and both prefer playing online Adventure games. This has some synergies with works by [18, 20] where Adventure games appear as the most preferred by girls. To some extent, genre game preference can also be explained by their goal when playing—knowing what no one else knows. If we use Bartle's model, we can classify them as achievers: people who love to get high scores. If they know what no one else knows they will score better, and want to prove their achievements with high level character and other things that show their success in the game [21]. Because Cluster 2 scored lowest in terms of genre preference, we decided to consider a second genre (Simulation: 24.5 %), which is in consonance with [18] findings. Preference for using cell phone among girls also confirms literature findings [18].

Concerning Clusters 1 and 2, composed by boys (96.4 %) and girls (72.4 %) respectively, we can see coincidences among type of favorite movie (Action), time spent online (more than 3 h), and what they do when not in school (playing with computer). Here we found a divergent result from an international literature review where, in general, boys tend to spend more time than girls online [18, 22]. These differences could be explained by gender similarities in Cluster 1 (96.4 % boys) by socioeconomics background similarities in Clusters 2 (81.2 % private school).

Worries with health issues are common to all tree Clusters. Maybe this can be explained by the fact that Brazilian kids are exposed to news programs, which treat this subject very often and always in a dramatic way, since it deals with life and death issues. Cluster 3 shows concerns about safety. This is a serious problem in Brazil predominantly in poorer zones.

They also prefer playing physical street games when they are not playing online games. This can be explained because from ages 7 to 15, kids need to develop their physical abilities, testing their skills. Cluster 2 shows interest in playing board games as well what coincides with [22] findings.

After analyzing these results, each of the personas needed to be "brought to life." For each of the personas, we wrote a narrative emphasizing their game preferences and interests. As said before, we were particularly interested in describing what motivates them to keep engaged to a game. This is very important when we aim to design a real fun educational game.

**Persona 1**

Miguel is 13 years old and lives in Brasília, Brazil's capital. Miguel is in the 8th grade at a private school, which is very close to his house. He walks to school and almost every day he is in a hurry. He doesn't like to wake up early in the morning and stays in bed as much as he can before getting ready to leave. He is the eldest son and lives with his mother, a teacher, and his father, a doctor. He has a sister, aged 11, and they are very close. They like playing the same online games: first person shooter and football. He likes playing games where he is free to roam around and interact with a realistic world, doing things, which he can't do in real life. There he can explore bad and good behaviors without real consequences, because when playing games he can always fix the problems he makes. When playing football online, what he likes best is the feeling of being someone else, very famous, and talented. He thinks it is very empowering to help his team win a game. Besides, there is the competition and Miguel loves to be the first on the ranking. Miguel wants to be an architect in the future and he dreams about studying abroad. When Miguel is not online on his laptop or studying, he likes playing real football with his friends. If he stays at home, he prefers watching TV, especially action movies with lots of car racing and fighting. Concerning social issues, Miguel is worried about health in Brazil. He thinks politicians are always lying and never keeping up with their promises of looking after people.

**Persona 2**
Julia is 11 years old and lives in Fortaleza, Brazil. She is in the 8th grade at a private school far from her house. After her parents got divorced, her mother, her and their dog, moved to live near the beach. Julia misses her father a lot because he doesn't visit her very often. Julia has to take a school bus everyday and this upsets her. She has to leave her house 1 h before class starts and always arrives very late at home when she comes back. The only good thing is that she can play on her cell phone on her way to school and back. Julia loves playing adventure and simulation game, especially those that can be played with other players. Now she is somewhat addicted to a game where she can craft things, build houses, and fight with enemies. This gives her a very good feeling of ownership and belonging. Besides, she must be very creative to survive. And when she doesn't know something, she can find a lot of information on how to play this game on Internet. She also likes the idea of learning how to get better and better in playing it. In the morning, before going to school, she does her homework as fast as she can to have more free time to play. Sometimes, after playing it, she watches TV. She loves American series and action movies. When her friends visit her, they play Seven Sins, a game where you have to run away from your friend ball attack. Concerning politics, she is worried about health issues. Once, she heard her mother saying that the government has used all its money to build stadiums for the World Cup and now there is nothing left to be invested in health care. She would like to talk about this with her mother, but she says that this is an adult subject.

**Persona 3**
Yasmin is 12 years old and lives in a rural neighborhood close to Belo Horizonte, Brazil. She studies in a public school in a mixed class of grades 6 and 7. She is a good student but hates math. Every day she has to go earlier to school to have tutoring classes because she failed her last test. Yasmin is the younger sister of three brothers and lives with her parents and grandmother. Before going to school, she studies, and helps her mother clean the house. When she comes back, she loves watching TV until it is time to go to bed. She loves Brazilian's soap operas. She used to play on her mothers laptop, but now she uses her new cell phone with Internet connection. Her mother has even allowed her to create a social network profile! She is very happy, because she no longer needs to go to her aunts' to access the Internet, although she cannot stay for longer than 1 h a day. Mother's rules! She

plays adventure games. She likes mostly those where you can choose your avatar and improve it while playing. Now she is playing almost everyday a game where she has to run away from a policeman, with lots of physical obstacles and places hard to access. When she accomplishes her game missions, she earns coins, which she can use to buy things, including making her avatar even nicer. She plays it with her cell phone and she can control her avatar movement by moving the phone. She must be very careful not to die! During the weekend she goes to church and she likes playing football. But she has to play with boys because her girl friends don't like it at all. She does not like politics. It seems to her that politicians only fight, that they are always saying bed things about each other and don't do anything good to us. She is worried with health issues, but in her opinion one of the main problems in Brazil is security: you can be robbed at anytime and no one helps you.

## 4 Conclusions

As a design tool, personas aim at connecting designers and users. Through the detailed narrative, we expect these three personas will help them to overcome the natural tendency of making product design decisions based on an idea of general user or on our own needs and preferences. This commitment to user-centered design methods is even more important when we aim designing a real fun and engaging educational game.

However, persona development methods are widely varied and the design team must decide which one would be appropriate to their project. We opted to use quantitative data for cluster assignment because we were interested in reaching a varied and large number of students.

Two Step clustering method provided three clusters, which is in accordance with design teams recommendation. Although quantitative techniques rely on statistical software for analysis, we have to interpret the information in order to determine their meaning in the context of our game. We did so based on this survey's results but also referring to prior study, when we could be face-to-face with our user.

Because we faced some problems in receiving all the questionnaires sent to teachers, we decided to confirm our results comparing it with similar studies or surveys. We found divergences but also similarities among them. As with most studies related to developing medium, some works are time-bound to the period when data were collected.

The process of mapping user's information and using them to create personas is still largely subjective. The method outlined in this paper provides one way of doing it, but it has its limitations. We believe that its real value will be confirmed during the game design process when it will be validated by using these three personas with real children.

It would be very important if other researches could perform quantitative methods on creating child-personas. This would help us enrich a methodology that can reach a larger set of users.

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# Web Press Carousel and His Effects Over News Memorization

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**Abstract** The use of carousel system in the websites is becoming a trend among the world's main web press publishers. Effects of two carousel variables over memorization of news were studied: Number of news in the carousel (7 or 14); Interaction mode with the carousel (Automatic or Manual scroll). 60 participants were divided into four groups of 15 elements each: 7 news into an automatic scroll; 14 news into an automatic scroll; 7 news into a manual scroll; 14 news into a manual scroll. Memorization was evaluated through evocation of news, by an open-response questionnaire after a carousels' exhibition. An interaction effect was observed. With 7 news, evocation was higher in the automatic carousel and slightly worst in the manual. With 14 news, evocation was worst in automatic carousel and

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slightly best in manual. Concerning the memorization of news, decisions about the carousel type to use, are not independent of the number of news.

**Keywords** Web carousel · Memory · Evocation · Usability · UX · Cognitive ergonomics · Design psychology

# 1 Introduction

The display of news through carousel formats on web pages is a common technique and is being quite widespread. There are few evidences to prove or measure the efficiency of this system. According to Pernice [1], the display of news in a carousel format, usually, shows the following characteristics: Appears at the top of the main page of a website (homepage); Occupies a substantial part of the visible screen for the user (page fold); Different contents appear in the same space; There is an indication that is possible to navigate between contents; The contents presented in each frame contains a large picture and a small amount of text.

Some carousel formats have an automatized movement, with a range of seconds between the highlighted content. There are also manual carousels formats, allowing the user to manipulate the content. Finally, the mixed ones have an automatic presentation of the content but at the same time allow the user to manipulate the content himself. Ordinarily, the images and the headlines of the elements displayed on the carousel system are clickable and send the user to a webpage, where the development of that same content is.

## *1.1 The Trend*

Putting publications through a carousel format is a way to transmit the most used information, as this allows to publish a variety of news in the same page area. However, it doesn't mean this is the best system to display information. At a favourable location, the carousel may be effective by attracting the users' attention on a specific content. Still, due to its dynamism and movement [2], it can become inappropriate and distracting when the focus should be other content within the very same webpage.

The wide use of this system by some media websites (we evaluated the Portuguese ones, in particular), is becoming a trend to highlight the news.

May those news headlines be retained in the memory on an equal form, when displayed on a carousel? Could it be the carousel the most appropriate system to show the important content on a website?

## *1.2 Other Studies*

In a usability test [3] where it was given to users the task to discover special promotions shown as news in a carousel system with automatic advance of 5 s, the task success rate was very low. In conclusion, was unadvised the use of carousel systems with automatic advance, for the following reasons: the movement takes the user to associate the text to an advertising content and its consequent devaluation; the probability to read an item that is on permanent turnover is lower than with static items. On the other hand, it was concluded that the presence of more than 5 elements in rotation decreases the capacity of recognition of all the elements displayed.

Other researchers [4] tried to realise by *eyetracking* if the display of news in rotary systems is effective. In that study, it was not measured the understanding index of displayed news, but when the users were confronted with questions as to indicate the most important news, it was notorious the inability and the indecisiveness by them. In turn, carousel systems with manual scroll received the largest number of clicks.

## *1.3 Objective*

Although there are references and other studies about the recent display systems, accompanied by sequentially images, commonly known as carousel system, it is noticed that the approach to all the system characteristics over the user interaction and memory process is scarce.

Previous concerns over this system issues, don't regard the effects of the quantity dimension and the possibility of interaction at the same time.

This study aims to understand the effect of these two independent variables over the process of news memorization: the number of news displayed on the carousel, 7 or 14 news headlines; and the possibility of user interaction, including an automatic scroll, which the user does not control or a manual scroll which allows the user to have full control of the carousel.

Both of these variables were manipulated using a slideshow (a reproduction of a carousel), composed by textual news headlines and accompanied by relational images, in order to understand the memorization performance on this type of system.

We are expecting that our dependent variable, memorization index (evocation of news) will be higher with less quantity of news and higher with manual scroll, because participant can change headlines at the speed he desires.

## 2 Method and Instruments

### 2.1 Participants

Participated in this study a sample of a 60 participants (33 male; 27 female) aged between 18 and 65 (x = 32.03) and with a level of education ranging the primary education and college education. The sample was randomized into four groups of 15 participants each.

### 2.2 Design

Participants were divided into four groups of 15 elements each: (G1) 7 news into an automatic scroll; (G2) 14 news into an automatic scroll; (G3) 7 news into a manual scroll; (G4) 14 news into a manual scroll.

To all participants were displayed a number of news headlines accompanied by related images.

The automatic scroll was parameterized to display a range of 5000 ms between each news headlines. This duration was set after the observation of the intervals practiced by the Portuguese online, which use the carousel system. The manual scroll was controlled with the mouse click

To avoid order effects, it was created news sequences. Three for the 7 news and other three for the 14 news. A counterbalance was made, thus, each group of 5 participants was exposed to the same headlines stream, as follows: Sequence A of headlines given to 5 participants; Sequence B of headlines given to 5 participants; Sequence C of headlines given to 5 participants.

### 2.3 Instruments

*Carousel.* A carousel system composed by a set of news headlines and images was created. Four versions of the carousels were conceived with the two types of scroll interaction (automatic and manual), and two different quantities (7 news headlines and 14 news headlines).

Each carousel slide had one image and one lower bar where was written the news headlines. All of these versions had an initial slide with the protocol instructions to the procedure and; one last slide linking the questionnaire and a gratitude note for the participants.

*Questionnaire.* A two versions questionnaire was made. A 14 questions version for the 14 news headlines carousels and a 7 questions version for the 7 news headlines carousels. Spite of the two versions, the questionnaire's format was similar. After the headlines' visualization, the participants proceed to the questionnaire (Google Forms format) where they were instructed to complete a number of questions using an open response approach. Each participant had to complete the sentence with what he remembered about the headlines previously read. A section of sociodemographic data was also on the questionnaire. Questions were mostly built by the grammatical assembly between subject and predicate, and participants were asked to complete the sentence using the reported speech (direct or indirect speech). After the questionnaire submission, an excel file was created for further SPSS analysis.

*News headline.* The news headlines, and the corresponding images displayed to the participants were taken from online publications of two important Portuguese media websites. The headlines were real and exposed to a professional editing criteria by the media. In this context, the news selected were indexed in 7 areas of interest: Economics, Sports, Science, Culture, Technology, Health and Politics.

When the 14 news headlines were displayed, each topic of interest was repeated.

### 2.4 Memorization Index

To classify the responses of the participants, a memorization news index (IndexM) was created. The index had four rating layers punctuated by a numerical value scale. With an increasing orientation, the index works as follows: when a response is given with references or terms that are not present on the news headline, or when there is no response at all, the score has a value of zero (0) points; when the response expresses an idea, although tenuous than it was reported on the news headline, and herein, it is regarded the reference to some terms with verb or noun features (it is not regarded any articles or adverbs) present on the original news headline, the scores has a value of 1 point; when the answer given by the participant conveys the idea of the news headline, even if he or she call on to synonyms or verbs of similar meaning, but not change the main content, the score has a value of 2 points; when the answer is the full transcript or reference (it is not regarded the absence or exchange of articles, when the perception of transcription is not distorted), the score has a value of 3 points.

The concept of this new rating index is based on the language functions of syntax and semantics. The first relates to the superficial aspects of language: its structure and shape, in a set of rules that combines the creation of words and sentences. The second relates to the significance of these same constructions. The structure of a word is necessarily linked to the semantics so that its meaning can be understood.

The adaptation of the "working memory model for the acquisition of speech" by Ellis [5] on the understanding of the information storage processes, it was essential to build the index's filter base. This model is based on three increasing filter layers on the acquisition of language, on the auditory inputs and on the vision inputs. We perceived that auditory inputs could be addressed as an internal resonance box inside the brain while reading information (in this case, in news headlines forms), since the participant ends up creating internal sounds, during the reading process, to assimilate what it was read.

Therefore, we have matched the first level, about the absorption of a phoneme, with the sound acquisition of phonemes during the exhibition and the display of the news headlines; the second level, the word acquisition, was matched with the second layer in the index (an answer with a word or term present in the news headlines); the third level, the acquisition of the sentence, was matched with the third and fourth levels of the index (when the participant expresses the full idea or transcribe the headline in a complete way).

### *2.5 Procedure*

The experiment took place in different spots such as classrooms and meeting rooms, but the isolation from external disturbances, which could influence the interaction, was a common matter. Each participant interacted with a computing device (laptop or tablet) individually and before one monitor, at least. A test protocol was established, explaining that the participant would read a controlled number of news (the series of 7 headlines or the series of 14 headlines) and how the display system should behave (with an automatic or a manual scroll). It was stated that the experiment evaluation was about the interaction between the sample and the system and not about the individual performance of each participant. There was no mention to the memory measurement.

Assured the allocation of one of the carousel versions to each participant, the sequence of slides was displayed only once. Given the visualization, it was not allowed to the participants a review of the headlines, they were sent directly to the questionnaire.

Before the passive monitors supervision, each participant filled in the questionnaire according to the information recovered from the memory. Whenever it did not happen, they were allowed to answer with "I do not know" or "I do not remember".

The experiment ended after questionnaire submission.

## 3 Results

Data of memorization index (IndexM) was converted for percentage. The maximum score (100 %) possible for the 14 news, was 42 (3 maximum score for evocation of each individual news * 14 news). The maximum score (100 %) possible for the 7 news, was 21 (3 maximum score for evocation of each individual news * 7 news).

**Table 1** Average and standard deviation of IndexM for scroll type and number of news

| | | Automatic | Manual |
|---|---|---|---|
| | | X = 35.4 sd = 17.8 | X = 32.9 sd = 15.1 |
| 7 headline news | X = 37.5 sd = 18.2 | X = 42.2 sd = 17.7 | X = 32.7 sd = 18.1 |
| 14 headline news | X = 30.7 sd = 13.9 | X = 28.6 sd = 15.6 | X = 33.1 sd = 12.1 |

Table 1 present average and standard deviation for each independent variable (number of news and type of carousel) as well for it two levels.

Relating type of carousel, the automatic had an average percentage of 35.4 and the manual 32.9 %, with only a difference of 2.5 %. Concerning number of news, the average percentage of 7 news was 37.6 and for the 14 news it was 30.7 % with a difference of 6.8 %.

As we can see in Table 1 and Fig. 1, variation of results is higher when the levels of each independent variable is cross analysed. For carousel with 7 news, IndexM percentage was 42.2 in the automatic scroll and decreased to 32.7 % with the manual Scroll. Thus is a difference in IndexM of 9.5 %, but with no statistically significant differences ($t = 1.457$; $p = 0.156$). For the carousel of 14 news, there is a IndexM of 28.6 % for automatic scroll, and for the manual 33.1 %. In the 14 news, there is an increase of 4.7 % from automatic to manual, but also with no statistically significant differences ($t = -0.872$; $p = 0.390$).

A vertical lecture of results, by column, show in Automatic scroll, a higher IndexM for 7 news (42.2 %) than 14 news (28.6 %), that represent a statistically significant difference ($t = 2.239$; $p = 0.033$) in the IndexM of 13.6 %. In the

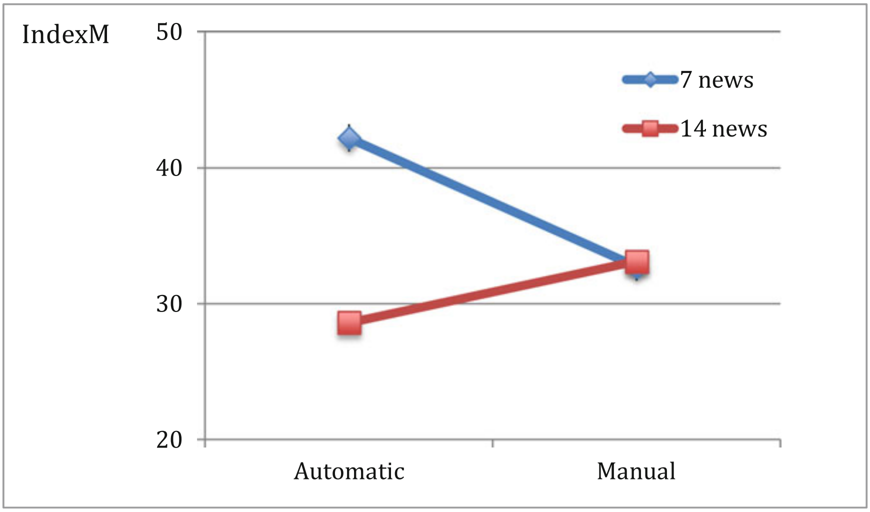


**Fig. 1** Average values of IndexM for scroll type and number of news

manual scroll, the values of IndexM for 7 and 14 news was very close, 32.7 and 33.1 respectively, with no significant differences ($t = -0.057$; $p = 0.955$).

For checking for interaction effects of quantity of news and type of carousel, a two-way anova was executed. There was no significant effects neither of quantity of news ($f = 2508$; $p = 0.119$) neither scroll type ($f = 0.364$; $p = 0.559$). Despite no significative interaction effect was observed ($f = 2.84$; $p = 0.097$), value of p, was close to a significant value.

## 4 Discussion and Conclusion

Through this study, the researchers wanted to understand which characteristics a carousel system should have to best contribute to the memorization and evocation of news headlines presented on webpages.

Regarding carousel, we were expecting that memorization would be higher with less quantity of news headlines and higher with manual scroll. First hypothesis is only true for the automatic scroll: memorization is higher for 7 news. In the manual scroll there is no difference in memorization of news between 7 and 14 news headlines in the carousel. The second hypothesis is not confirmed. In the manual carousel there was not a better memorization than in the automatic.

For a clear understanding of these results, we may consider an interaction effect of number of headline news and type of carousel. With 7 news, evocation was higher in the automatic carousel and slightly worst in the manual. With 14 news, evocation was worst in automatic carousel and slightly best in manual. Thus if the carousel is automatic, there is a better memorization of few headline news, but if carousel is manual there is no difference in the number of news memorized. However, as the interaction effect was only close to significant value, we cannot definitely support this conclusion without increasing the sample of the study.

At the beginning, it was predicted that the memory index was higher in the carousel system with a manual scroll than with an automatic one. This hypothesis has not been proven by statistical tests, which showed there were no significant differences among the memory index both in manual and automatic scroll.

To try to explain this result, it is assumed that the time set for change of news on automatic scroll is approximately equal to the time the participant need when using the manual scroll (5000 ms). This is a possible explanation to understand why there are no differences in memory index in both scroll conditions.

It was confirmed that users can have better memorization over news headlines when they are presented in lower quantity, an evidence in previously studies performed over the memory.

What this research also intended to prove was that when the carousel system was controlled by the users it would ensure a better memory. In contrast, the automatic system would have a worse memorization.

It was not possible to obtain favourable results to confirm the above hypotheses, but they leave clues for future studies and indicate that the time set for the display of the news headlines is a component key to take into consideration.

Another important aspect was the use of a qualitative rating system, which involves some subjectivity.

Although the results cannot prove all the hypotheses, it has been concluded that the carousel system is a good mechanism to put in evidence and to understand the memory processes.

Some limitations of the study may be presented. Between the 11th and the 15th of January 2016 (period of the data gathering for this study), the Portuguese news media broadcasting had three main subject driving their agenda. At national level, the presidential running campaign was very intense at a political level, influencing the amount of news published around this topic. The second most important topic was the crisis around the sportive performance of one Portuguese football club, usually a strong and an historical candidate to win the national title. Finally, the international agenda of news was highly focused on the death of two artistic celebrities, whom touched the heart and feelings of different generations. Both deaths were caused by cancer. A more detailed analysis of results, not presented here shows the percentage of correct answers in news related with the above topics were higher than the other topics. Keywords like “cancer”, “Porto” (name of the football team) and “presidency” were spontaneously mentioned in answers even when they were not part of the original title of news. The presence of the three mentioned topics on the news might have influenced results. Due to this cognitive reinforcement, some users felt confident enough to add terms or keywords to news headlines even if those terms were not written on the original title of the news.

Size of sample in each group, should be at least of 30 participants, in order to be increase power of statistical tests, and get stronger support to our conclusions.

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# Part II
# Usability and User Experience in Design

# Using Video Game Patterns to Raise the Intrinsic Motivation to Conduct Accessibility Evaluations

**Alexander Henka, Andreas Stiegler and Gottfried Zimmermann**

**Abstract** Even though many national and international guidelines exist to support the development of accessible web applications and to provide guidance, a high number of web applications are still inaccessible. For a large number of web authors, it is hard to imagine how persons with disabilities would interact with their web applications. Therefore, people with disabilities often end up not being considered part of a products' target audience, and accessibility testing is experienced as an additional burden or skipped entirely. In this paper, we present an approach that augments an accessibility evaluation process with video game patterns to raise intrinsic motivation to conduct accessibility tests. This paper describes work in progress and illustrates how video game patterns can be pragmatically transferred and implemented in a non-game environment.

**Keywords** Human computer interaction · Gamification · Accessibility · User-centered accessibility evaluation · Intrinsic motivation · Video game patterns

## 1 Introduction

Several studies focusing on the aspect of web development found that web authors (any person involved in the development of a web application) have issues to understand and classify accessibility guidelines correctly. Also, for a large number of web authors, it is hard to imagine how users with disabilities would interact with their web applications [1, 2]. Therefore, people with disabilities are often not

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considered part of a products' target audience, and web authors often experience accessibility testing as an additional burden or skip it entirely. This results in a high number of web applications that are inaccessible or come with significant barriers [3, 4]. The reasons for this unfavorable situation are numerous. With a high number of web applications being inaccessible, even though guidelines (e.g., WCAG 2.0 [5]) exist to provide support and guidance, there is a need for research on the topic of how to motivate web authors to conduct evaluations to improve the overall accessibility of their products.

Delivering adequate tools is definitely one way to approach this problem, but web authors also often lack the awareness about requirements people with disabilities might have [1, 2]. Just following guidelines is insufficient, as accessible design requires understanding of the interaction needs of people with disabilities rather than just satisfying the conformance of web applications towards guidelines.

Consequently, several studies have shown that accessibility evaluation tools, focusing only on guideline conformance, can't fully grasp the accessibility of a web application [6–8]. It has been pointed out that accessibility issues are highly user centered [9] and characterized as: "*[Accessibility is, when] specific users with specific disabilities can use it [the software] to achieve specific goals with the same effectiveness, safety and security as non-disabled people*" [6]. According to this view, a barrier is a condition that prevents a specific user from achieving their specific goals, taking into account that each user has specific traits and is using specific assistive technologies.

Work has been done to raise the level of awareness among web developers for the needs and requirements of people with disabilities. One particular approach consists of conducting accessibility tests (using personas and walkthrough techniques) providing first-hand experience on how a web page would be perceived and navigated by individuals with various disabilities [10, 11]. Besides raising awareness, it is important to build motivation for web developers to conduct accessibility tests.

Many national laws, such as the act on the equal treatment of disabled people of the state of Baden-Württemberg (Germany) [12], require that web services of public authorities be accessible. In many instances, authorities may even be sued if their web services exclude certain parts of the community by being inaccessible. Hence, web companies working for public agencies are required to develop and provide accessible applications. Yet, state-controlled accessibility acts cannot be the optimal solution, since they cause an extrinsic motivation only. As soon as the act or its enforcement is gone, the motivation is gone. We therefore suggest focusing on stimulating intrinsic motivation of web authors to conduct accessibility tests.

Intrinsic motivation can be seen as been motivated by the own behavior, or self-motivated [13]. According to the *self-determination theory*, one has to satisfy certain psychological needs to stimulate intrinsic motivation: *autonomy*, *competence* and *relatedness* [14, 15].

*Autonomy* refers to activities done for a distinct interest or personal benefit. Key factors for a high autonomy are that activities are performed in a non-controlling environment and supported by choice and rewards as informational feedback.

A task that provides a high autonomy level is more likely to be perceived as intrinsically motivating.

*Competence* represents the need for challenges and the feeling of being effective. Examples for competence are the perception of being appropriately challenged, to have the possibilities to acquire new skills, or to receive positive feedback.

*Relatedness* is experienced when a person feels connected to others, which provides companionship and social interaction. Typical examples are team sports. As pointed out by Ryan et al. [15], one can experience this form of relatedness also with computer-generated personalities, such as non-player-characters (NPCs) in modern video games.

Watson et al. [16] highlighted the relationship between the accommodation of these psychological needs and their positive effects on the intrinsic motivation in learning environments and casual games. Aparicio et al. [17] discussed a basic process on how to apply autonomy, competence and relatedness to business workflows using gamification patterns.

In this paper, we survey our user-centered accessibility evaluation framework [18] for its abilities of raising intrinsic motivation to conduct accessibility tests. We will discuss this by augmenting our evolution process with game patterns. Gamification is usually defined as the use of game design elements in non-gaming environments or contexts [19]. Yet, instead of applying generic gamification patterns such as high-score lists or badges, we adopt and adjust strategies from applications that provide a high level of intrinsic motivation by design: video games. These games form a widespread part of modern culture and are considered fun and enjoyable without requiring any extrinsic motivation.

In our previous work, we extracted video game design patterns, which are independent of their visual and conceptual representation. We found fundamental design principles allowing video games to produce such a powerful intrinsic motivation [20]. Boiled down, these patterns are: providing *exploration*, which targets the curiosity of the player; *immediate feedback* on user interaction; a model of *rewards* or *penalties* rendering them measurable and expectable; *limited action space*; and providing *challenges*.

This paper surveys our user-centered accessibility evaluation framework [18] under the consideration of video game patterns to bolster its potential to raise intrinsic motivation. The intention of this paper is to illustrate how our findings on video game patterns [20] can be pragmatically transferred to a none-gaming environment. The remainder of this paper is structured as follows: Sect. 2 introduces the general concept of our user-centered accessibility evaluation framework. Section 3 provides an overview of our findings on video game patterns. Section 4 reveals the findings of our survey and illustrates how video-game patterns can be applied to our evaluation framework. Section 5 provides a discussion on our survey and an outlook on our next steps.

## 2 User-Centered Accessibility Testing

Our evaluation framework, introduced in [18] and [21], accommodates the needs for a user-centered accessibility evaluation by focusing on the end-user's requirements. It uses persona objects and the applications' use cases to determine the accessibility in a semi-automated fashion by running acceptance tests on the base of needs and preferences of an end user using a web browser. Figure 1 illustrates the components and basic workflow of the framework.

The general principle is to use personas as a vehicle to transport the end-user's needs. In the discipline of user-centered design, personas are an established concept [22, 23] to keep the focus on the end-user's requirements during the product development. Furthermore, they have proven to be effective to convey and raise awareness for the needs and requirements of people with disabilities [9, 24–26]. Besides traditional persona descriptions, containing images and a background story, we use machine-readable representations of personas, called *persona objects*. These objects represent different types of people with impairments. Each persona object contains technical and semantical requirements, based on relevant WCAG success criteria and semantic requirement statements [18], such as the need of having a "*search field*" visible in the top right corner of the screen. Besides that, each persona object contains a specific interaction pattern, which reflects the interaction style for a certain type of disability. A persona-object representing a persona that is blind, for example, would contain interaction patterns to use keyboard navigation and to consider speech output.

The accessibility acceptance tests are conducted on the base of a web application's use cases. For each use case, a user scenario is derived. In our approach, a user scenario is as an instance of a use case, but with specific usage data. A scenario

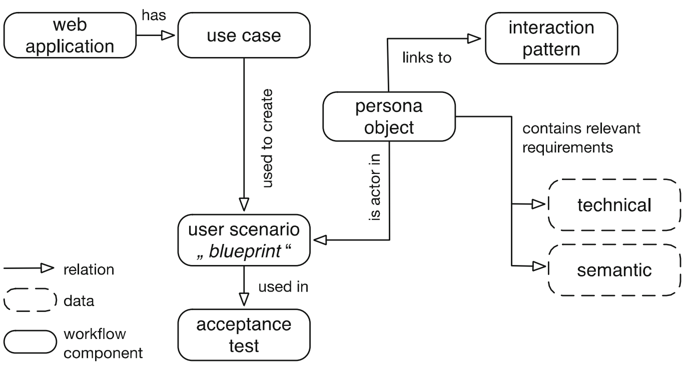


**Fig. 1** Overview of the general concept and the accessibility evaluation process. A use case of a web application is used to create a user scenario ("blueprint"), which in turn is used in an acceptance test. A persona object serves as an actor in a blueprint. A persona object contains relevant technical and semantic requirements for a specific type of user. It also links to interaction patterns that satisfy these requirements

typically consists of a setting, a plot, and an actor performing the task described in the scenario. In such a scenario, the person objects are the actors carrying out the use case using their defined interaction metaphors and requirements. The outcome, also known as the level of accessibility relating to an application's use case, depends on their accessibility requirements and the specific navigation patterns. As each actor will approach such a scenario differently, the result could be different amongst actors; hence, a user scenario can be reused and checked under different circumstances by substituting the actor—aka the persona. To underline its reusability, we call a user scenario a *blueprint* [18].

The tests are executed in a semi-automated fashion live in the web browser. They simulate the way the respective persona would interact with the web application. To simulate the user interaction, we use *Selenium* [27], an open source framework that is capable of simulating user interaction (e.g. interacting with buttons or filling in web forms) in the browser. Technical conformance requirements are checked according to the WCAG 2.0 guidelines. Discovered accessibility issues, semantical requirements, and WCAG success criteria that need human verification, are highlighted on the web application, and presented to the tester for further validation. However, some parts of a web application are not necessarily part of the applications use cases, the legal notice for example, and needs to be tested using established techniques if not covered in a blueprint. Therefore, we do not advocate substituting established accessibility evaluation techniques. We see our approach as an addition to established workflows and as a support for a more user-centered accessibility evaluation [18].

## 3 Video Game Patterns

Even at first glance, a computer game feels quite different from the average office application. Yet, when taking a closer look at the actions a player performs, the difference between a game such as an *MMORPG* ("Massive Multiplayer Online Role-Playing Game") and filling out timesheets is small: Both consist of many repetitive, yet long-lasting tasks. Still, the game is highly intrinsically motivating, with players willingly investing hours per day, whereas the office application, even if extrinsically motivated through a monthly salary, feels cumbersome and like a burden. This is the very difference the video game patterns try to approach. We extracted game design patterns from actual games in order to apply them to non-game contexts. We found five distinct patterns: *Development*, *action space*, *exploration*, *challenge* and *reward*, of which we will outline the ones relevant for this concrete application.

## *3.1 Providing Exploration*

Designing virtual worlds is a core aspect of game design. Curiosity is a driving force of mankind and many games offer opportunities for exploration, hidden treasures and secrets throughout their game world. Some games rely on it almost entirely, for example the many open-world games, including the popular *Minecraft*. Yet, in order to achieve believable exploration, a virtual world has to be designed, which is typically out of scope for a gamification application. There are, however, other ways to provide exploration, for example by offering a vast pool of elements of which players can choose from, without requiring a consistent virtual world. Good examples of such games are trading card games, such as *Hearthstone* or *Magic: The Gathering*. These games feature hundreds of cards, of which a player has to select a small amount to build their deck from. Just discovering all the cards and their synergies can be highly motivating to some players.

## *3.2 Immediate Feedback and Reward*

Reward is one of the key principles of gamification research. It is also the most obvious difference between conventional office applications and games. Games almost always design a reward mechanism. This insight led to the countless high-score lists, customer points and bonus programs one can encounter ranging from supermarkets to airlines. Yet, the precise mechanisms on what we identify as a reward and what triggers respective reactions in the brain are not fully understood. There are, however, some aspects of reward that seem to be important for human decision making.

First of all, reward in games is often comparable, and in most cases even measurable. Comparable in this context means that one can identify that one reward is smaller or larger than another, whereas measurable means that reward can be mapped on a numeric scale, allowing the user to identify by how much the two rewards are different. The notion of comparable and measurable rewards is derived from information theory: Two elements are called comparable, if there are meaningful equality, less-than and greater-than relations. On the contrary, two elements are called measurable, if a distance measure between the elements can be formulated. Colors, for example, are neither comparable nor measurable: red is not the same as yellow, so we can identify that they are not identical, but red is neither greater nor less than yellow. Badges, on the other hand, are comparable: A user can compare their collection of badges to the collection of other users. Badges also often come in different grades, like having an expert badge and a regular badge for different levels of contribution. A user can clearly see that an expert badge is greater than the regular version, but they do not really know what the difference is. Experience points, finally, are comparable and measurable. If a user gets 100 experience points (XP) for one task and 50 XP for another, they clearly see that one task was rewarded by twice as many experience points.

An important aspect of reward—or penalties—in games is that it is immediate. An action in a game rewards a player right once the action is completed. This is important for building user satisfaction—and thus intrinsic motivation—as the perception of competence is much stronger if a player is able to realize what the precise action was that caused the reward. Receiving some XP for slaying a dragon in a game can contribute a lot more to a user's perception of competence than receiving their salary. Both are awarded for the actions performed, but the salary cannot be linked to a specific action, even though the salary is a much stronger form of reward.

### 3.3 Limited Action Space

The notion of action space originates from artificial intelligence research and describes the number of options one can choose from at a given point in time. There are multiple aspects regarding the action space that are important for gamification. When selecting an option from a pool of alternatives, it is important that the user is presented with a fully observable action space, i.e. with every possible option. Game GUIs typically design their usability around this concept, whereas office applications often neglect it. Consider an application like Microsoft Excel, where a single action—such as altering the format of a cell—is spread over dozens of buttons and menus, which are not visible at the same point in time. Games, unlike many office applications, can tailor their underlying business task to have a limited number of options to choose from, whereas an office application has to deal with the full complexity of text formatting. Having a limited action space, however, is one of the key ingredients to make decisions enjoyable for humans. This builds on the notion auf *autonomy*: A user can only feel satisfaction in their own reasoning process if they were able to perceive all possible options and—more importantly—they knew that they perceived all possible options.

### 3.4 Challenges

The design and dramaturgy of designing a game's challenges is an essential part in game design. A common approach is game flow [28]. Game flow is a concept of keeping challenges offered by the game in balance with the skill progression of the player. From a more abstract perspective, game flow is dealing with learning effects of the user. One example of applying flow to gamification for elderly was demonstrated by Korn [29]. Yet, typically, challenge is not a design parameter of gamification. This is obvious, as the challenge in a business application does not originate from gamification, but from the underlying business task.

In some applications, however, particular challenges can be designed and integrated into a gamification strategy. In those scenarios, challenges are often designed in a playful way, coupling them with immediate feedback, a limited action space and reward mechanisms. Such a game is called a “parallel game” where actions of the actual business task become a resource in a game, linking the business task and the game closely together. Such approaches start blurring the border between gamification and serious games.

# 4 Intrinsic Motivation in User-Centered Accessibility Testing

We surveyed our accessibility evaluation framework for its potential to raise intrinsic motivation by considering the video game patterns described in Sect. 3 and in [20]. This section outlines our findings.

## 4.1 Limited Action Space

Personas *limit the action space*. In a nutshell: When creating personas, the goals, needs, and requirements of the end users are clustered, with each cluster forming the foundation of a persona. Therefore, personas reduce the complexity from satisfying “the user”, an unknown and fuzzy entity, to a manageable number of personas—with concrete requirements [22, 23].

We use personas in our evaluation framework to cluster accessibility requirements. The persona objects consist of a persona-specific interaction pattern and a set of relevant WCAG 2.0 [5] success criteria. Instead of testing for the fuzzy “user”, one can test the accessibility e.g. only for blind people, by using a persona representing an impairment of blindness. Hereby, we *limit the action space* from all accessibility guidelines and users, to a handful of personas and their concrete requirements.

Personas can also stimulate *relatedness*. According to [23], personas work because they tell stories; stories about people, their lives, traits and characteristics, which projects a mental model of the persona into the viewer’s head. With such a model, one can predict how the persona would react in certain situations. This can also be witnessed for fictitious characters from movies, books or video games. After the last episode of our favorite TV show has been aired, we could predict how the show would continue, by using the mental model that we have of our beloved characters. The quantity of fan-fiction[1] written for various genres emphasizes this [30]. It was stated by Ryan et al. [15], that the relatedness can also be met by

[1]Fan-fiction is the term for stories based on TV shows, movies or video games created by fans.

computer generated personalities and artificial intelligence. We therefore argue that personas can create a feeling of relatedness, which is important for raising intrinsic motivation. As stated in various work [9, 24–26], personas have proven to be effective in accessibility teaching and the evaluation process. They are suitable vessels to induce empathy for the needs and requirement of people with disabilities. By using walkthrough techniques, like the barrier-walkthrough introduced by Brajnik [6], one can make use of the mental model to state the accessibility and usability of a web application by raising questions like: "*Would Anna know what to do at this point of the purchasing process?*" or "*Is it clear for Anna what to enter in this web form?*" (Where Anna is the name of a persona). Besides personas, we found the *limitation of action space* pattern in the form of the *blueprints*. Blueprints cluster the web elements that a user has to interact with to process a certain use case. Instead of being confronted with the complete space of web elements, the web author can focus on meaningful abstractions.

## *4.2 Providing Exploration*

Personas provide *exploration.* Exploration is about discovering new things for a dedicated purpose. By choosing a certain user scenario and a specific persona, playing the role of the actor, one can follow their own interests in discovering the accessibility of a web application. Conducting accessibility tests for a dedicated disability only—which will happen when choosing a certain persona—can be based on one's curiosity to discover how accessible certain use cases for certain personas are.

Game patterns that provide *exploration* should never degrade the affectivity and efficiency of the underlying process. A way to make exploration work in an accessibility evaluation environment is to make it optional and implement it as a supplementary aspect of the evaluation process. An exploration approach can consist of providing a first-hand experience on how a web page would be perceived and navigated by individuals with various disabilities. A similar approach is presented by Ates et al. [31]. They illustrated a wearable display, which simulates how visual impaired people perceive their environment. The simulation can be used to conduct rapid accessibility checks, by viewing a web application through the wearable display. We argue that simulating the interaction and perception of other impairments could refine such an approach. The interaction between the tester and the web application could be adapted accordingly to the specific interaction paradigm and perception model of a persona object. Doing so, we could establish an optional approach focusing on exploration through the means of specific personas.

## 4.3 Immediate Feedback and Reward

Running accessibility evaluations based on personas and blueprints will provide *immediate feedback and reward*. As argued in [21], reward and feedback in video games usually occurs right after the action that caused it, contradictory to real-life examples, where feedback and rewards (or penalties) are often distributed a long time after the action that triggered it. When validating the conformance of a web application to guidelines (using an automatic tool), one may get the feedback that the application fulfills some guidelines and violates others. Yet, how such a conformance impacts the end users is not evident and may only be revealed later on as user tests are conducted.

Running an accessibility acceptance test with a specific persona in a defined user scenario (blueprint) will immediately be rewarded by the feedback that this user scenario is accessible (positive case) or inaccessible (negative case) for that specific type of persona. As a web author, one can state that a particular user scenario is accessible for a certain type of disability (pictured by the persona); hence, our framework rewards accessibility testing by showing for which persona—or more precisely, for which type of impairment—a certain user scenario is accessible. A web author can have the satisfaction of knowing for what types of users a web application is accessible. Or to use video-game language: It lets web authors experience that they had just unlocked the accessibility for *Anna*.

It is essential for the enjoyment of many video games that they provide some form of development; hence, the player needs the feeling of being successful and making progress [21]. By unlocking the accessibility of more personas we could provide the foundation for a persistent and measurable progress. In consequence, this can stimulate the need for *competence,* since the tester can measure their effectivity by seeing the personas getting unlocked.

## 4.4 Challenges

To stimulate intrinsic motivation a person needs to have the feeling of being optimally challenged accordingly to their skill level [15, 16]. In video games, this can be achieved by adapting the environment to the skills of the player, e.g. by altering the strength of virtual opponents or providing other ways to support the player.

Challenges in accessibility testing cannot be implemented easily, since the business task (accessibility evaluation) implies the challenge by itself. The goal of web authors should be to provide usable and solid products, and therefore accessibility testing should remain efficient and effective and not be clustered with additional obstacles. However, the usage of personas and user scenarios enables a tester to choose their own challenges. Web authors can select which user scenario they wants to examine, they can select which personas should play the role of the actor and, since we are using WCAG to state the technical accessibility, the conformance level (A, AA or AAA). With these options at hand, a web author may choose a combination of scenario, persona and conformance levels that corresponds to their confidence and skill level. This pattern can be found in many modern role-playing video games, where players can choose, driven by interests, confidence and the own skill level, which quest they will take next.

Yet, we do not advocate testing only for a subset of accessibility issues, or that a tester should only test those scenarios for which they feel confident. In the end, a web application needs to be accessible for all personas in all use cases! The topic of our research is to identify ways to raise intrinsic motivation: If someone can choose a test scenario that fits their current skill level, it will certainly aid their psychological needs for *autonomy* and *competence*. If a tester feels effective and has acquired new skills, their confidence may raise and they might become eager to test other personas and scenarios, which could be an asset especially for beginners.

## 5 Discussion and Outlook

In this paper, we examined our accessibility evaluation framework [18] for its potential to stimulate intrinsic motivation to conduct accessibility tests, considering video game patterns [20]. We illustrated which parts of the framework are augmented by video game patterns and how this can stimulate intrinsic motivation. We found evidence that the usage of personas, and conduct of accessibility evaluations on the basis of use cases, have the potential to stimulate motivation. However, we also identified some drawbacks of our approach, which could diminish motivation.

The goal of gamification in our approach is to raise intrinsic motivation on web developers. Yet, the underlying task—accessibility and usability testing—should not be degraded in terms of effectivity. Therefore, the gamification approach must be optional; otherwise it would become part of the underlying process, which we intend to enrich. If a web developer has to click through gamification interfaces to solve a task, they are forced (hence, extrinsically motivated) to participate, undermining the gamification goals we want to achieve.

Therefore, we are not entirely satisfied with the idea that, in order to state the accessibility, a web author has to define a blueprint at first. We see that this could lead to frustration, if one has to define multiple blueprints to state the accessibility of a web application. The creation of a blueprint would therefore not be optional and will certainly diminish the motivation factor. Yet, we are convinced of the motivating aspects of blueprints. In [21] we described the concept of defining a blueprint by capturing the use case interaction with a real person (e.g., the developer). It is a common task for web authors to test their own application. This interaction can be captured and used as a blueprint, which would ease the creation of a blueprint; hence, we could reuse a web author's mandatory task.

Another factor that can diminish motivation in our approach is that the evaluation is conducted by simulating the interaction live in the web browser. This implies that a tester can retrace the interaction flow, but has to wait till the evaluation has finished to observe the complete result. Despite the motivational factors, this is not optional! Hence, a tester is forced to view the complete interaction, which can take a while depending on the user scenario. We plan to undertake more research on how we can "fast-forward" the interaction to skip the live interaction part, thus making the observation optional. The issue is, that we cannot just jump to a corresponding HTML element, because for some personas navigation is an integral part of the evaluation and part of the specific interaction pattern, e.g. keyboard navigation for blind personas.

Our research on this topic is not finished and we are continuing our examination on how intrinsic motivation can be raised to conduct accessibility tests. Our evaluation framework represents a solid foundation for further tests. This paper highlights the game patterns that we have found in our evolution framework and discusses their possibilities to stimulate intrinsic motivation. We are currently preparing a user test to discover if the revealed game patterns can indeed lead to a stimulation of intrinsic motivation. The test will be conducted by comparing our framework to other accessibility evaluation methods, like automatic accessibility conformance checkers, walkthrough techniques, and checklists.

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# Criteria Based Approach to Assess the User Experience of Driving Information Proactive System: Integration of Guidelines, Heuristic Mapping and Case Study

**Mathilde Duczman, Eric Brangier and Aurélie Thévenin**

**Abstract** In the case of driving informational systems, techniques can be used to improve user experience in an automotive context, especially regarding proactive systems. Heuristic inspection techniques are classical methods to assess interfaces aspects and identify problematic components for human computer interactions. This paper deals with the problem of the integration of four sets of criteria which are (1) Accessibility (Perceptibility, Temporal Adaptation, Simplicity, Comprehensibility, Robustness); (2) Practicality (Guidance, Workload, Explicit Control, Adaptability, Error management, Consistency, Significance of codes, Compatibility); (3) Emotionality (Degree of control, Challenge, Degree of Independence, Fantasy, Trust, Sensorial interest, Cognitive interest, Effort, Satisfaction), and (4) Persuasiveness (Credibility, Privacy, Personalization, Attractiveness, Solicitation, Priming, Commitment, Ascendency). It shows that criteria are complementary between each other to identify main ergonomic problems but it also highlights the need to consider further aspects for heuristic inspection of a driving information proactive system.

**Keywords** User experience · Heuristic mapping · Driving information systems · Proactive systems

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# 1 Introduction

Pleasure, compatibility, satisfaction, efficiency… All of these are notions that a user might look for better interactions with a product.

In Human-Computer Interactions studies, plenty of criteria, norms, recommendations and methods exist to assess quality of products and technologies for measuring how they are, or not, adapted to human characteristics and to their activities and tasks. These tools are generally aiming to a same objective; to identify potential problems for interactions and using and to formulate recommendations in order to improve User, Customer and Product Experiences. User Experience is often associated with a broad range of fuzzy and dynamic concepts, e.g., experience, emotion, affect, aesthetics, persuasion and, also social and cultural dimensions. Hassenzahl and Tractinsky [1] defined UX as "a consequence of a user's internal state (his expectations, needs, motivation, etc.), the characteristics of the designed system (complexity, purpose, usability, etc.), and the context within which the interaction occurs". UX could vary according to human characteristics, context parameters and also one product properties.

This paper is aiming at observing how an Inspection method with criteria of Accessibility, Practicality, Emotionality and Persuasiveness can be realized on a driving information proactive system, which acts on behalf of user's need by displaying personalized and contextual information. The goals of this study can be defined as follow:

- Assessing a driving information proactive system, named as Driving Coach;
- Proposing an integrative method for inspection of such system;
- Discussing about relations between heuristic inspection and User Experience studies.

In this paper, we'll first present our set of criteria for heuristic inspection. We'll then focus on problem and method that we've conducted to assess the driving information system. Finally, we'll present and discuss our main results before concluding on the contributions of our study and considering perspectives for further researches about User Experience studies in automotive sector and in other fields of research.

# 2 Integrative Approach of Heuristic Inspection

## *2.1 Heuristic Inspection and Criteria for User Experience Design*

In field of ergonomics or Human Computer Interactions, heuristic inspections are classical methods invoked by experts in evaluation phase or design process to assess how a product is adapted to human activity. Inspection techniques aim to formulate a judgment about one product's quality by pointing out usability and interaction issues that might occur in a using process. Heuristic inspection is a relevant method to assess in early stage of using process, how the integration of a product can affect user experience.

A heuristic is a general principle that can guide a design decision or be used to critique a decision that has already been made in the design of interfaces. Heuristic evaluation has been developed by Nielsen [2] as a method for organizing the assessment of a system using a set of simple and general heuristics. The general idea behind heuristic evaluation is that UX specialists independently assess interfaces to arise potential usability problems. Heuristic evaluation is best used as a costless time evaluation technique; it is easier to attach a lot of the usability problems that come up. In general, grids criteria do not include data on these forms of persuasion in interfaces. It is therefore necessary to develop a method of inspection technology dedicated to persuasion.

In the early days of computing, “accessibility” helped the designers to be focused on a primary concern: guaranteeing, allowing, and facilitating the access of the users to the system. In spite of the fact that it is generally about designing for users with disabilities (inclusive design), accessibility is also aimed at casual users. But the designers should not only take care of that issue, the notion of “usability” arose to emphasis the need for simple interactions. This ergonomics concept arose out of HCI studies that took place during the 70s. Those were focused on users' cognitive reasoning processes, workload, satisfaction and constraints with the final goal to guarantee that systems fitted their cognitive, perceptive and motor characteristics. It was defined by the ISO norm 9241 as “the effectiveness, efficiency and satisfaction with which specified users can achieve specified goals in particular environments”. Efficiency is about ensuring that the user can achieve his/her goal through the system. Efficacy means optimizing the ratio effort/performance. Satisfaction aims at preserve and develop the user comfort. Usability (efficiency, efficacy, satisfaction) has been fundamental concepts for years.

Thereafter, “emotional design” has added a new perspective to those two key concepts: it implies thinking about the non-instrumental qualities of a system with and affective point of view. The goal is to fulfill a user's need beyond mere usability, such as the wish for social bounds or for a hedonic experience, leading to positive experiences. In reality, user centered design fields of practice seek compatibility between the users' characteristics and the systems they interact with. This can be studied from several different angles: technical, social integration or appropriation. All those aspects are not covered by accessibility, usability and emotion, hence the need for a new concept. Nowadays, persuasive technology is at the summit of that design evolution. The target of that set of techniques is to take benefit of the characteristics of new technologies in order to modify the users' attitudes and/or behavior. This is the field of the “captology” (Computer As Persuasive

TechnOLOGY). Indeed, as Information and Communication Technologies are more and more ubiquitous and interactive, the creation of adaptive and incessant persuasive dialogue to change users' attitudes is becoming easier than ever.

## *2.2 Sets of Criteria*

Heuristic Inspection can be approached with different kind of criteria in order to point out different ergonomic issues about a product. The set of criteria that we are going to present result from previous researches about human computer interactions and about the way humans are integrating a product or a technology to their activity [3–5]. Bastien et al. [5] have proposed an integrative approach of criteria for heuristic inspection, which take in account technological evolution and different aspects that a user would consider to use a product. These criteria are articulated on functional experience and lived experience that a user might have with one technology, respectively considering issues about accessibility, practicality and then emotionality and persuasiveness (Fig. 1).

- Accessibility refer to first criteria aiming at improving relations between human and technology by making content of information accessible for anyone. Criteria of accessibility are taking in account basic biomechanical and psychophysiological constraints which need to be consider in a design process in order to make a product or a service accessible to specific population.
- Practicality then goes further accessibility aspects by considering cognitive mechanisms of humans. Criteria of practicality are focusing on ease of use and high human and technical performance by taking in account reasoning mechanisms and workload issues. Bastien and Scapin [6] propose a grid of 8 criteria, aiming to adapt one product to specific human tasks and objectives.
- Criteria of Emotionality are later considering other user needs that go beyond the physical and cognitive ones considered earlier through notions of Accessibility and Practicality. Further studies have demonstrated that a user might also express non-functional needs such as fulfilness, self-expression, aesthetics which might influence interactions with a product and then a whole experience with it. De Vicente and Pain [7] propose a set of 9 criteria which integrate pleasure and attractively aspects.
- Persuasiveness then integrates further non-instrumental dimensions aiming at guiding and inducing human behavior through several aspects such as credibility commitment. A set persuasiveness criteria have been proposed by Nemery and Brangier [8] and consider principles of social persuasion.

**Criteria to assess user experience**

**Criteria for Access**
Perceptibility: Interfaces and information should be presented in a way of being perceived, whatever the type of users.
Simplicity: Ease of use.
Temporal adaptation : Replace contents should be spread according to different format without any loss of information.
Comprehensibility: Information should be easy to understand for every user. Contents should appear in a logical and a predictable way
Robustness: System and its content should resist to unexpected solicitations and be sufficiently reliable for satisfying all users

**Criteria for Pragmatic**
Guidance: Capacity to advice, inform and lead the user during his interactions with the product.
Workload: Perceptual and cognitive load should be reduced in order to minimize errors and increase the dialogue efficiency.
Explicit Control: Capacity to take in account explicit actions and let the user control elements of the interface in order to reduce errors
Adaptability: Capacity of a system to behave contextually according to needs and preferences through flexibility of the system and through taking in account level of user experience
Error Management: Capacity of a system to prevent and reduce errors through capacity of Error protection, Quality of error messages, Error
Consistency: Design choices (Procedures, Labels, Commands…) need to be maintained in similar contexts and be different in different contexts to reduce research time
Significance of codes: Adequacy between a displayed information and its reference terms in order to avoid inappropriate actions
Compatibility: Match between user's characteristics (memory, perception…) and task's characteristics

**Criteria for Emotion**
Control: Degree of control that the student likes having over the learning situation.
Challenge: Degree that the student enjoys having challenging situations during the instruction.
Independence: Degree that the student prefers to work independently, without asking others for help.
Fantasy: Degree that the student appreciates environments that evoke mental images of physical or social situations not actually present.
Confidence: Refers to the student's belief in being able to perform the task at hand correctly.
Sensory interest: Amount of curiosity aroused through the interface presentation.
Cognitive interest: Refers to curiosity aroused through the cognitive or epistemic characteristics of the task
Effort: Degree that the student is exerting himself in order to perform the learning
Satisfaction: Overall feeling of goal accomplishment.

**Criteria for Persuasion**
Credibility: Giving enough information to the user allows him to identify the source of information to be reliable, relevant, expert and trustworthy.
Privacy: Do not persuade the user to do something that publicly exposes his private life and which he would not consent to do.
Personalization Consider the user as a person and consequently develop a personal relationship
Attractiveness: Capturing the attention of the user to elicit emotion and induce favorable action
Solicitation: Booting the relationship by first temptations
Initiation (or priming): Helping the user to do as the system wants him to do
Commitment: Involve, engage and adhere to the objectives of the system
Ascendency: Control the user, submit the user to have his/her total involvement

**Fig. 1** Mapping of criteria of accessibility, practicality, emotionality, and persuasiveness

## 3 Problem

In automotive sector, studies about user experience are increasing by focusing on how to design better experience with embedded technologies. Through plenty of methods and techniques, researchers are questioning how automotive systems can lead to a positive experience. Knobel et al. [9, 10] have described for example different methods to improve experience with advanced driving assistance systems in automotive context. In the case of driving informational systems, we can wonder what techniques can be used to improve user experience in an automotive context. Heuristic inspection techniques are classical methods, often the first step, to assess interface aspects and identify problematic components for human computer interactions. We can then wonder if our set of criteria is adapted to make an inspection of a driving information system and if these tools can help experts to propose recommendations to improve interfaces for a better experience with a driving information system.

# 4 Method

## *4.1 Context and Request*

This study takes place in a research context about interactions between humans and proactive driving information applications.

Proactivity of an application can here be defined as the ability of a device to act on its own initiative, on behalf of user needs and intentions, in order to help him to realize his activities [11, 12]. The particularity of proactive technologies is working in an autonomous way, and proposing personalized information at the good time, regarding to user's activity [13, 14].

In this context, we need to assess the ergonomic qualities of a recent proactive driving information application. The assessed application is a first version of a driving informational system, that we'll call "Driving Coach" in this paper (Fig. 2).

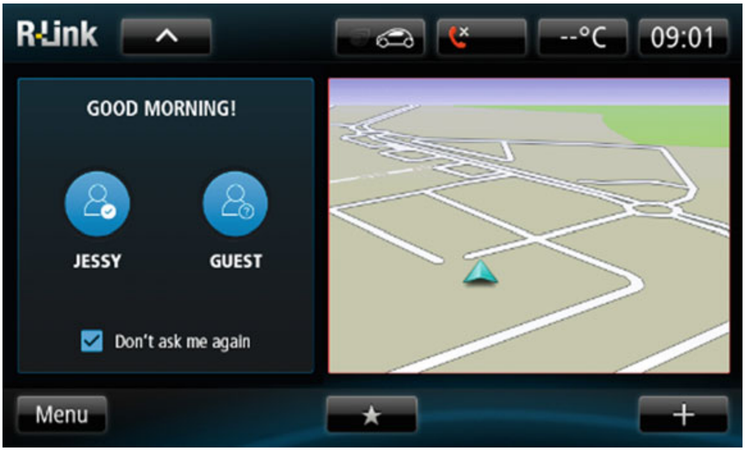


**Fig. 2** Screenshots of driving coach application

Driving Coach aims at assisting drivers in their daily trips by helping them to plan their route and to anticipate dangerous events on their usual routes. The main particularity of the application is to work within a proactive behavior; indeed, in a contextually and autonomous way, the application is displaying personalized information without intervention of the user. The application is presenting two types of features: proactive features and classical features. Proactive features are composed of 3 main functionalities:

– Real-time information on driving style,
– Predictions of Destination,
– and Predictions of Dangerous spots.

Classical features gather characteristics which work in a reactive way, meaning it works with user control, like statistic information about previous trips.

Two modes are proposed to user for interacting with Driving Coach: Challenge Mode and Companion Mode. Each of them gives access to the same functionalities, except that with Challenge Mode, User can collect rewards such as points and badges. Regarding theses main features, suggesting personalized and evolving content, we can wonder how a user would interact with proactive functionalities and feels about this application by using it. As we were wondered to formulate recommendations to improve the interfaces, we can then study how an integrative approach of both functional and non-functional criteria can lead us to assess the driving proactive informational system.

## *4.2 Inspection Protocol*

By focusing on an integrative approach of criteria of accessibility, practicality, emotionality and persuasiveness, our main goal was identifying components of the interfaces and interactions related to persuasive aspects, motivational aspects, practicable aspects and accessible aspects.

First, observations and test of Driving Coach have been conducted during two weeks by three experts in real driving context to study how the application behaves. Then, heuristic inspection has been realized by experts on each interface and functionalities of the application, considering every aspect of accessibility, practicality, emotionality and persuasiveness. For the inspection, experts have classified 111 elements of the interface into a spreadsheet according to each criterion, in order to identify positive and negative components for accessibility, practicality, emotionality and persuasiveness (Fig. 1). Positive and negative elements that have been noted were then turned into percentages in a spreadsheet in order to identify the contribution of positive and negative elements on accessibility, practicality, emotionality and persuasiveness.

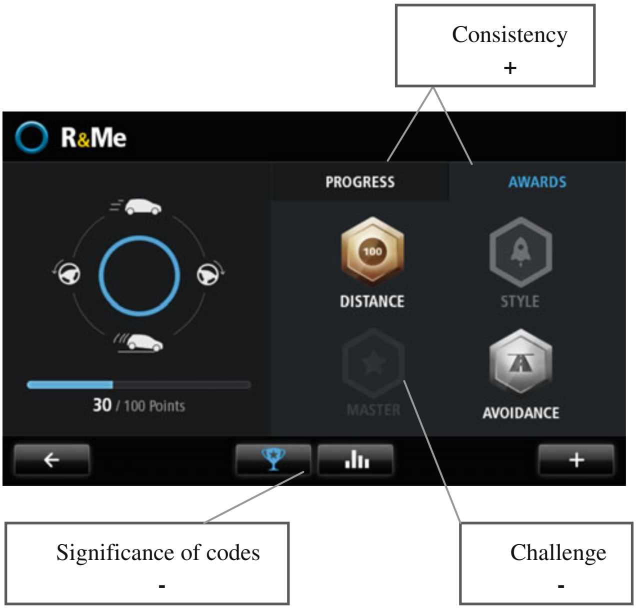


**Fig. 3** Screenshots of the interface after heuristic inspection

After having classified elements into the spreadsheet, we have pointed problematic components for accessibility, practicality, emotionality and persuasiveness on screenshots of the interface (Fig. 3).

In this inspection, two criteria have not been considered because experts have judged them too general to assess ergonomic problems for this kind of application: Temporal adaptation and Usability. The first one refers to the ability of a system to offer different format to replace contents. As the application is an embedded information system, information is spread in one type of content on one device only so we will not assess the application according to these criteria. The second one then refers to usable character of functionalities. As usability is a general criteria defined with further ones presented below, this criteria would be too restrictive to assess usability of the interface.

# 5 Results

## *5.1 Results About Accessibility*

In terms of Accessibility, information of the application is presented in a perceptible way, with simplified language and big font size. However, among interface components which influence accessibility, we notice that 69 % constitute real problems for accessibility. Indeed, inspection has revealed important problems of robustness and comprehensibility. We've first noticed sensitivity towards external and unexpected solicitations, mainly because of proactive features such as real-time information on driving style, predictions of destination and predictions of dangerous spots. Information are not reliable because they are not displayed at the good moment according to driving activity and are not always related to user's habits, which also create problems of comprehensibility because they are not appearing in a predictable way.

## *5.2 Results About Practicality*

In terms of Practicality, we identified that 76 % of the components are problematical. Criteria of adaptability were partially respected. Reactive features such as the possibility of choosing between 3 ways if displaying information and the possibility to choose "don't ask me again" when displaying information testifies good flexibility and allow the user to reach his objective through different ways. However, proactive features of the application are not really taking in account level of user experience; user cannot personalize frequency of predictions occurrence and predictions are not displayed contextually, which would be the main goal of a proactive application.

The Driving Coach application also indicates problems with workload and compatibility with the current task. Information about real-time driving style and rewards while driving can compromise the driving task because of high information density and because of a lack of accuracy of information content. We also notice a lack of capacity to advice and lead the user through proactive features due to late feedback of the information testify. This can compromise the guidance. Moreover, design choices are not consistent in the way the two using modes are presented and labels are not significant which can increase research time of information.

Finally, criteria of explicit control was difficult to assess in this case study. The user can control some elements on the interface like choosing between using modes or different ways of displaying information. Nevertheless, proactive features cannot be assessed according to capacity of taking in account explicit actions. Indeed, the application takes partially decisions for user, so we cannot consider this part of criteria.

## *5.3 Results About Emotionality*

In terms of emotionality, we identify some aspects contributing to fantasy such as representation of well-being in driving context or target to hit for catching point, which can evokes pleasant situations. We also notice several problematic aspects, representing 60 % of emotional components. Regarding criteria of challenge;

rewards to win are limited, only virtual and are not proposed in a logical way. Then, means are limited, almost missing to let the user trust in his/her own abilities to achieve correctly a task. Indeed, predictions are not displayed immediately and contextually which is preventing the user to measure his/her success.

### *5.4 Results About Persuasiveness*

Regarding persuasiveness, several graphical elements and personalized messages solicit user's interest and capture his attention, such as colors on dynamic circle which are calling for action, predictions which catch the interest and lead to positive emotions. However, we also notice problematic components, which represent 52 % of persuasive components of the interface. Limited and virtual rewards constitute problems for credibility and commitment. Plus, we notice no external justification when displaying information on dangerous spots or destination. This can be problematic because the interface doesn't inspire confidence and the user might not be involved into a process with continued interactions.

### *5.5 Synthesis: Map the Inspection*

Figure 4 shows a synthesis of the heuristic inspection according to the 30 criteria. During his/her interactions with the application, the user will mainly encounter accessibility and practicality problems. The application is first not robust and comprehensible enough, principally due to proactive features which can trouble satisfaction and reliability. The functionalities then present important problems with adaptability and compatibility, especially regarding proactive features one more time. Those are not flexible enough to take in account level of user experience and user's context to be displayed and might trouble dialogue efficiency. These problems are fundamental because components of the interface which constitute problems for accessibility and practicality of the product directly affect psychophysiological and cognitive mechanisms and might negatively impact efficacy, efficiency and satisfaction regarding the product.

Regarding emotional and persuasive aspects of the interface, components of fantasy and attractiveness could capture the attention of the user and create positive experience during the very first interactions. Nevertheless, other components of the interface were negatively assessed because of limited challenge properties which not stimulate user in his interactions. Proactive features of the interface such as real-time information on driving style, destination predictions and dangerous spots predictions also negatively impact trust, cognitive interest, credibility and ascendency. These properties may trouble pleasure, confidence and more widely commitment in his interactions with the whole product on long-term using.

| Criteria for Pragmatic | |
|---|---|
| Guidance | - |
| Workload | - |
| Explicit Control | + |
| Adaptability | - |
| Error management | o |
| Consistency | + |
| Significance of codes | - |
| Compatibility | - |

| Criteria for Access | |
|---|---|
| Perceptibility | + |
| Temporal Adaptation | - |
| Simplicity | |
| Comprehensibility | - |
| Robustness | - |

**Criteria to assess user experience**

| Criteria for Emotion | |
|---|---|
| Degree of control | o |
| Challenge | - |
| Degree of Independance | - |
| Fantasy | o |
| Trust | - |
| Sensorial interest | - |
| Cognitive interest | - |
| Effort | o |
| Satisfaction | - |

| Criteria for Persuasion | |
|---|---|
| Credibility | - |
| Privacy | o |
| Personalization | - |
| Attractiveness | o |
| Solicitation | o |
| Priming | o |
| Commitment | - |
| Ascendency | - |

**Fig. 4** Synthesis: positive and negative assessment (+/−) of the sets of criteria

## 6 Discussion

The aim of this study was assessing the ergonomic quality of a driving proactive information system with technique of heuristic inspection with four existing inspection grids.

As a conclusion, we can first say that criteria are complementary between each other to reveal problems which can occur during interactions between a user and a driving information proactive system. Some of them were more adapted to assess proactive features like robustness and compatibility, which appeared as important qualities for assessing the ability of a proactive application to display information in an autonomous way. Criteria of comprehensibility, guidance and adaptability also appeared fundamental to assess accuracy and relevance of the information proactively displayed by the system in a driving context. Regarding persuasive and emotional aspects, we consider criteria of trust, privacy and personalization important to assess proactive system. As it is evolving and taking decisions for the user, these aspects can impact interactions between user and the system and influence the human-machine relation over time.

Nevertheless, these criteria mainly focus on the interface characteristics and not on intelligent and proactive properties of a driving information system. Indeed, the particularity of such systems is being interactive and evolutive according to environmental context and user's characteristics. It can sometimes provide unexpected content for user and it appears essential to determine in what context and how to display these information to ensure efficacy, efficiency and satisfaction over time.

Few research are also focusing on specific criteria which can ensure acceptance of proactive technology [13, 14] by taking in account relevance or transparency for example. We can then wonder how these criteria can be integrated to existing tools for heuristic inspection.

This study finally highlights the need to consider further aspects for realizing heuristic inspection of driving information proactive systems. It also highlights the need to consider time as an important factor to study human computer interactions with intelligent proactive systems which are personalized and evolve over time. Heuristic inspection helped us to identify main problems for human-computer interactions but longitudinal view would be necessary to understand how proactive features and interface qualities of such a system can affect acceptance and using over time.

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# Analysis of the Effect of Varying Trash Receptacle Distance to the Littering Behavior of Metro Manila Bus Commuters

**Jan Alessa J. Balane, Karina O. Felizardo and Ma. Christina Beatrice F. Lopez-Tan**

**Abstract** Seventy five percent of Filipino commuters use public transportation such as Public Utility Buses (PUBs). Trash receptacles are frequently placed in areas of transit facilities perceived to have the largest number of passersby. Thus, placement of receptacles does not consider convenient distances to its target users and may not elicit the optimal trash disposal behavior. This study aims to analyze the effect of varying trash receptacle distance to the littering behavior of Filipino bus commuters. Survey with 100 respondents determined three distances that commuters claim are inconvenient in properly disposing their trash. With this, observations were conducted in a bus terminal along Epifanio Delos Santos Avenue, the busiest highway in Metro Manila. The number of commuters who disposed trash properly and who littered were counted for three determined receptacle distance. Statistical analyses showed the dependence of littering behavior on trash receptacle distance and strong correlation between trash receptacle distance and littering behavior.

**Keywords** Filipino bus commuters · Trash receptacle · Disposal behavior · Litter · Human factors

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# 1 Introduction

Litter is identified as one of the primary causes of pollution in Metro Manila. During times of calamity such as typhoons, floating plastic bags and bottles are commonly seen on sidewalks as well as on video clips featuring public places on television news. Clogging of these littered trashes is considered to be a large contributor to flooding in the Philippines. As such, several trash receptacles are found in public areas to accommodate trash from pedestrians.

The distance of a trash receptacle from a reference area should elicit the most effective trash disposal behavior. This study focuses on the distance to the trash receptacle from a point of reference and its effect on the tendency of the Filipino bus commuters to litter or to dispose of their trash properly.

The study aimed to determine if there is a correlation between trash receptacle distance and littering behavior, and determine whether littering behavior is dependent on the distance of a trash receptacle from a reference point.

# 2 Methodology

## 2.1 Sample Size

Three setups were used in the study. Each setup refers to specific distance from a chosen reference area to the trash receptacle. The distance used in each setup was determined using an online survey conducted to bus commuters wherein respondents were asked how many steps away a trash receptacle should be in a bus terminal setting for it to be considered inconvenient to throw their trash. Three of the most selected range of steps (i.e. *15 or more steps is inconvenient*) was used as the setups in the study.

Using the work sampling formula for determining the sample size, the required number of observations per set-up was computed (Table 1).

## 2.2 Setup

For uniformity purposes, the waiting area, where most of the bus commuters stay, was established to be the reference point for each set-up. The trash receptacle was positioned at a tested distance from the midpoint of the waiting area. The distance for each set-up was determined using a survey of 100 respondents. For all the set-ups, the same trash receptacle was used to eliminate variability due to individual preferences.

**Table 1** Required number of observations per set-up

| Distance | 9.9 m (15 steps away) | 13.208 m (20 steps away) | 23.114 m (35 steps away) |
|---|---|---|---|
| Acceptable limit of error (%) | 11.20395 | 10.88358 | 9.43027 |
| Total number of observations needed | 71 | 73 | 65 |

## 2.3 Data Collection

During off-peak hours, Filipino bus commuters who were at the set reference area were observed. A commuter seen eating, drinking, or smoking by an observer was considered as a potential subject and was observed until a disposal behavior was carried out. A count was added to proper trash disposal behavior once a potential subject stood up, walked and then disposed of his trash into the trash receptacle set by the researchers. Frequency increased as this action was done by a qualified, potential subject. On the other hand, frequency of littering behavior was recorded when a trash was dropped on the floor, left on the bench, or thrown around the trash receptacle by the potential subject. Those who were observed but have left the reference area without any disposal behavior shown were not considered and counted.

## 2.4 Data Analysis

The Test of Correlation was used to determine whether there is a relationship between trash receptacle distance and proper trash disposal, and trash receptacle distance and littering behavior.

The Chi-Square Test for Independence was then used to determine the independence or dependence of trash receptacle distance and littering behavior.

## 2.5 Data Presentation

An online survey was conducted to determine the distance to be used for each set-up. The result is shown in Table 2. The three distances with the most frequency were used for observing the littering behavior.

The frequency of littering behavior for each distance for each set-up is summarized in Table 3.

**Table 2** Survey results

| Distance | Frequency |
|---|---|
| more than 10 steps away | 17 |
| **more than 15 steps away** | **18** |
| **more than 20 steps away** | **25** |
| more than 25 steps away | 14 |
| more than 30 steps away | 8 |
| **more than 35 steps away** | **18** |
| Total | 100 |

**Table 3** Frequency of littering behavior per setup

| Actual frequency | | | | |
|---|---|---|---|---|
| | 15 steps away | 20 steps away | 35 steps away | Total |
| Disposed properly | 26 | 25 | 12 | 63 |
| Litter | 45 | 48 | 53 | 146 |
| Total | 71 | 73 | 65 | 209 |

# 3 Results and Discussion

## *3.1 Test of Correlation*

The researchers tested if there is a correlation between distance and littering behavior. The number of steps was converted into meters, with one step equivalent to 0.6706 m. Table 4 shows that distance and proper trash disposal behavior have a −0.98363 correlation coefficient which indicates a strong negative correlation. Thus, as the distance between the trash receptacle and the point of reference increases, less number of Filipino bus commuters tends to dispose trash properly. On the other hand, it is seen that distance and littering has a strong positive correlation with a correlation coefficient of 0.99090. As the distance between the trash receptacle and the point of reference increases, more Filipino bus commuters resort to littering.

**Table 4** Test of correlation results

| Distance | Littering behavior | |
|---|---|---|
| | Disposed properly | Litter |
| 9.9 | 26 | 45 |
| 13.208 | 25 | 48 |
| 23 | 12 | 53 |
| Correlation coefficient | −0.98363 | 0.99090 |
| Coefficient of determination | 0.96753 | 0.98189 |

Moreover, the coefficient of determination denotes the proportion of the variance in the littering behavior that can be predicted from the trash receptacle distance. A coefficient of determination of 0.96753 means that 96.753 % of the variance in proper trash disposal can be predicted from the distance while a value of 0.98189 means that 98.189 % of the variance in littering can be predicted from the distance.

## 3.2 *Chi-Square Test for Independence*

To test whether there is a significant relationship between trash receptacle distances and littering behavior, the Chi-square Test for Independence was used. The following hypotheses were tested:

$H_o$: Trash Receptacle Distance and Littering Behavior are independent.
$H_1$: Trash Receptacle Distance and Littering Behavior are not independent.

A 5 % significance level was used in the calculations. The null hypothesis would be rejected if $p < \alpha = 0.05$.

The expected frequency for all levels of each frequency was calculated and was then used to calculate for the Chi-Square Random Variable (Fig. 1).

The p-value obtained using Minitab was 0.038. Since this value is lower than 0.05, the null hypothesis that trash receptacle distance and littering behavior are independent is rejected.

**Chi-Square Test for Association: Littering Behavior, Trash Receptacle Distance**

Rows: Littering Behavior Columns: Trash Receptacle Distance

| | 15 Steps Away | 20 Steps Away | 35 Steps Away | All |
|---|---|---|---|---|
| Disposed Properly | 26 | 25 | 12 | 63 |
| | 21.40 | 22.00 | 19.59 | |
| Litter | 45 | 48 | 53 | 146 |
| | 49.60 | 51.00 | 45.41 | |
| All | 71 | 73 | 65 | 209 |

Cell Contents: Count
Expected count

Pearson Chi-Square = 6.210, DF = 2, P-Value = 0.045
Likelihood Ratio Chi-Square = 6.558, DF = 2, P-Value = 0.038

**Fig. 1** Chi-square test of independence results

## 4 Conclusion and Recommendation

The results of this study indicate that there is a strong relationship between trash receptacle distance and proper trash disposal, and trash receptacle distance and littering. Moreover, the results prove that the littering behavior of Filipino bus commuters is dependent on distance from available trash receptacles. The farther away the trash receptacle is from a person, the more likely that person will resort to littering, instead of properly disposing of his trash.

Due to the limitation of Statistical Analyses applicable on the study, a general numerical optimal distance could not be determined for recommendation. However, alongside compliance to regulations for placement and design of receptacles, it is recommended that Philippine transit facilities place their trash receptacles at minimized distances from commuters to elicit proper disposal behavior.

Of the three setups, the 9.9-m setup yielded the most optimal results, with more bus commuters disposing trash properly and less of them littering. 9.9-m is the maximum distance that commuters are willing to walk to dispose of their trash, and at this distance, the least amount of people who littered and greater amount of people who properly disposed trash were observed. Therefore, it is recommended that trash receptacles be placed at most 9.9-m from the waiting shed, the area where most commuters stay. This will significantly reduce amount of litter observed gaining several benefits including a cleaner and more inviting terminal and lower risk of non-compliance to the Anti-Littering Law.

Finally, it is recommended that trash receptacles be placed at most twice 9.9 or 19.8 m from each other. Following this setup will elicit proper trash disposal behavior. In addition, by maximizing the distances between trash receptacles, the company may minimize the amount of trash receptacles they need to purchase, lowering maintenance costs.

# Using Digital Thermography to Analyse the Product User's Affective Experience of a Product

**Rafaela Q. Barros, Marcelo M. Soares, Márcio A. Maçal, Ademário S. Tavares, Jaqueline A.N. Oliveira, José R.R. Silva, Aline S.O. Neves, Robson Oliveira and Geraldo O.S.N. Neto**

**Abstract** Although there are usability techniques that evaluate the user experience through the process of design and evaluation of consumer products, not always the researcher has the knowledge if the experience reported by the user at time of search matches fully with the actual experience felt by user. This study conducted a usability evaluation of a sample of users during manual handling of soda PET packaging by comparing the user-reported experience and the actual experience felt measured through usability analysis techniques and thermography. Thermography aimed to capture images from the volunteers radiated heat body parts to associate them with any emotional excitement while handling the product. Also proved that thermography has proven to be effective to measure users' satisfaction (felt experience) in handling consumer products.

**Keywords** Thermography · Affective experience · User's product · PET bottles of soft drinks

## 1 Introduction

The various techniques for evaluating usability, such as the conventional format of questionnaires, interviews, usability tests and focus groups may limit the comprehension of the user-product interaction because they do not provide objective measures and do not have the ability to capture the dynamics of the experiment in real time.

Jenkins et al. [1] comment on the subjective level of accuracy of such tools for evaluating usability, which analyze their results depending on: (1) the perception of

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each of the individuals of the experience and the context and (2) the ability to interpret and express the feelings of these individuals.

In this context, the researcher besides trying to understand the product-user interaction has to deal with the diversity of products in different usage scenarios and moreover should be prepared to understand a variety of complex responses.

In this sense, Falcão and Soares [2] argue that usability considers the quality of products and systems by analyzing the human-task-product interaction. The authors explain that even though usability is a tool used to improve product development and interfaces, this is still not enough to optimize the human-product interface.

Tullis and Albert [3] explain that usability uses metrics to measure a user's experience by means of a design and evaluation process that helps to identify potential usability problems. Moreover, some measures are used to facilitate the analysis and conduct of usability tests, such as by using usability models. But not always the researcher does not always have factual knowledge if the experience reported by the user at the time of the research fully matches the experience that the user actually underwent. The difference between what is reported and, in fact, felt becomes an unknown for the researcher.

Thus, to investigate the user-product interaction, this research study conducted an evaluation of usability of a sample of users when handling of PET bottles containing soft drinks.

To do so, we compared the experience reported (usability evaluation) and measurement of the experience felt, more objectively, by using an infra-red thermography technique. In addition, an analysis will be made of the effectiveness of this tool which enables the temperature of thermal images to be measured in real time at the moment when users are interacting with the PET bottles of soft drinks.

## 2 Methodology

The methodology of this research was organized into two field studies: (1) Field Study I—Usability evaluation (2) Field Study II—Thermography. For Field Study I, 12 participants (8 female and 4 male) were recruited, while Field Study II, 11 volunteers were selected (7 female and 4 male).

The method for selecting the sample had the following inclusion criteria: individuals reporting no pathological condition of the upper limbs in the previous year and the exclusion criteria were patients with a report on a pathological condition of their upper limbs in the previous year. This exclusion criterion is justified since, for this study, the product to be evaluated cannot be evaluated if a volunteer is mited in the use of his/her upper limbs.

The first step of the experiment was based on the study by Silva [4]. In that study, an assessment was made of the level of difficulty of opening of five types of plastic soft drinks containers. The Likert scale was used to assess the level of the users' satisfaction. The results of this research indicated that the package represented by Fig. 1a was considered difficult to open and that of Fig. 1b was considered easy to open.

Thus, in Field Study I—evaluation of usability, 20 users were asked to open the top of two models of soft drinks bottles (Fig. 1a, b). Then, a usability evaluation was made to analyze the users' satisfaction level as to the level of difficulty of opening the PET bottles based on the Likert scale [3].

As for Field Study II—Thermography, the experimental procedure consisted of three stages: (1) preparing the participants and monitoring the air conditioning of the ambiance, (2) measuring the reference measures, (3) capturing thermal images at the Laboratory for Ergonomic s and Emerging Technologies (ErgoTE, in Portuguese) of the graduate program of Design at the Federal University of Pernambuco, Brazil.

The results of the steps of the experiment were analyzed using software corresponding to each technique (described below) and compared with each other and the usability analysis.

## 3 Field Study on Usability

For the first step of the experiment, different types of PET bottles were selected in accordance with the study by Silva [4]. In this study, the author assessed the level of difficulty of opening five types of soft drinks PET bottle. To do so, the Likert scale was used to assess the level of user satisfaction. According to the results of this research, PET bottle 1 (Fig. 2a) and PT bottle 2 (Fig. 2b) were selected because these were considered easy and difficult to open, respectively.

Thus, 12 users were asked to open the tops of the two different soft drinks PET bottles (Fig. 3). Then, a usability evaluation was conducted to analyze the level of the users' satisfaction as to the level of difficulty of opening them based on the Likert scale by Tullis and Albert [3].


**Fig. 1** Plastic bottles considered difficult (**a**) and easy (**b**) to open (*Source* Silva [4])


**Fig. 2** PET bottles considered easy (**a**) and hard (**b**) to open (*Source* Authors)

**Fig. 3** Participants in the act of opening the soft drinks PET bottles (*Source* Authors)

The choice of this scale enables an analysis of the users' satisfaction regarding the opening of the two models of PET bottle chosen. This scale has extremes corresponding to the degree of positive or negative affirmation by which respondents assess their level of agreement or disagreement with what was requested. Five options were presented: very satisfied, satisfied, moderately satisfied, dissatisfied and very dissatisfied.

Thus, this scale let the participants express their satisfaction in degrees of agreement with a positive affirmation or in disagreement with a negative affirmation, thereby enabling them to compare and define which of the PET bottles was the most or least difficult to use.

**Analysis and results of the experiment**

The responses to the usability evaluation were organized according to the participants' level of satisfaction and presented the following results: as to PET bottle 1, seven respondents reported being very satisfied and four were satisfied. As for PET bottle 2, one respondent reported being very satisfied, three were satisfied, five stated that they were indifferent (moderately satisfied), two were dissatisfied and one was very dissatisfied.

Thus, it can be seen that as to PET bottle 1, the responses were clustered at two levels of positive satisfaction, thus indicating that it was less difficult to open, while as for PET bottle 2, the responses were more spread out among the alternatives presented. Thus, we can conclude that in this study, most respondents preferred PT bottle 1 as this was easier to open.

## 4 Field Study on Thermography

The experimental procedure of this study consisted of three stages: (1) preparing the participants and monitoring the air conditioning of the ambiance, (2) measuring the reference measurements, and (3) capturing the thermal images.

Initially, a pilot study was conducted, with participants chosen by convenience, in which they were requested to perform the task of opening the tops of soft drinks PET bottles 1 and 2, the intention being to generate a stimulus that can be recorded using the change in temperature of the face.

Moreover, thermal images of the palms positioned at the front and the side of the face were recorded (Fig. 4) in order to register the heat radiated when handling the PET bottles. For this, a digital thermal camera Flir E40 was used located 1.0 m away and in front of the volunteers.

Each volunteer was invited to sit comfortably in a chair with a suitable posture at a table. Monitoring and measuring the temperature and air velocity was performed using a digital thermo-anemometer MDA—II, Minipa/CE.

Statistical analysis of the data was carried out with the aid of SSPS19 software, on which the Shapiro-Wilk test between the variables measured was applied. The Wilcoxon Signed Ranks tests was also used to investigate the difference between

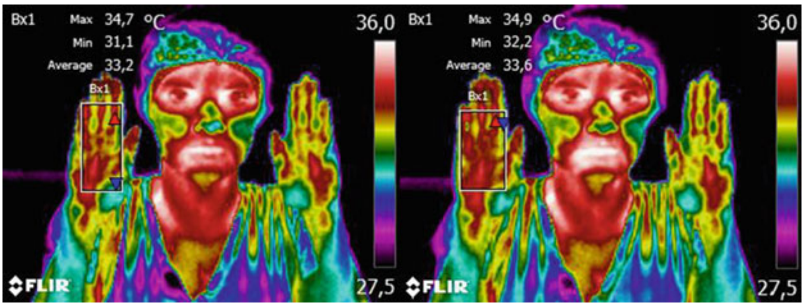


**Fig. 4** Comparison of thermal images before and after opening Bottle 1 (*Source* Authors)

the average temperature of each ROI obtained before and after opening the bottles. The Wilcoxon test showed a statistically significant difference ($p < 0.05$).

The radiant temperature of the hand was defined by (ΔT) of the minimum, maximum and average temperature found in the ROI of the images. Figure 4 shows two images of User 10: the first obtained before opening Bottle 1 with a maximum temperature of 34.7 °C, minimum of 31.1 °C and an average of 33.2 °C.

In the second after it was opened, the temperatures recorded were: maximum of 34.9 °C, minimum 32.2 °C and an average of 33.6 °C according to the temperature palette of the thermographic camera that ranged from 27.5 to 36 °C.

**Analysis of the experiment with Thermography**

The analysis of the study was started from the pilot study data undertaken with three volunteers. Thus, the results of this analysis revealed that there was no significant temperature difference (ΔT) in the thermal images of the face of the volunteers. So it was not possible to measure the emotional excitement based on identifying the facial thermal impressions of individuals.

This same result was observed during real study. Because of this, we analyzed the records of the thermal images of the hands to measure the level of heat radiated on the surface of the palm based on the physical stimuli arising from opening the soft drinks PET bottles.

Silva et al. [5] consider that manual dominance while opening a top is related to an increase in the muscularity capacity of the individual. For this reason we will examine if the muscular effort expended when opening the top of the PET bottle is associated with the increase in metabolic activity with a consequent temperature in the regions of the hands.

For each thermal image captured, the region of interest was defined in accordance with the outline of a four-sided polygon on the palmar surface of the hands and fingers. This procedure was adopted because of the higher concentration and visualization of the areas with a temperature difference.

The statistical analysis of the data was performed with the aid of SSPS19 software, on which the Shapiro-Wilk test between variables measured was applied. The Wilcoxon Signed Ranks test was used to investigate the difference between the average temperature of each ROI obtained before and after opening the bottles. The Wilcoxon test showed a statistically significant difference ($p < 0.05$).

Thus, the average of the temperatures found in Bottle 1 was 0.32 °C, the standard deviation of 0.34 and the median 0.3. As to Bottle 2, the average obtained was 0.073 °C, the standard deviation of 0.79 and median 0.1. Therefore the difference of the medians obtained was 0.24 °C (DIF1–DIF2).

The radiant temperature of the hand was defined by (ΔT) of the minimum temperature, maximum and average temperatures found in the ROI images. Figure 4 shows two images of User 10, the first obtained before the opening of Bottle 1 with a maximum temperature of 34.7 °C, a minimum of 31.1 °C and an average of 33.2 °C.

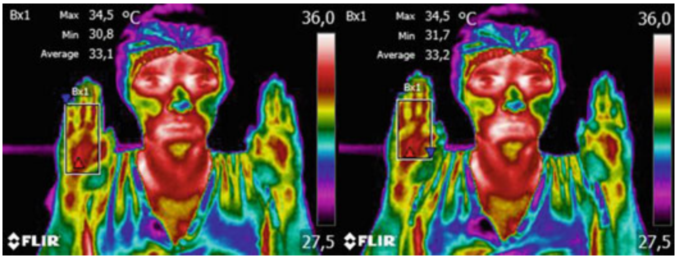


**Fig. 5** Comparison of thermal image before and after opening Bottle 2 (*Source* Authors)

In the second after it was opened, the temperatures recorded were: maximum of 34.9 °C, minimum 32.2 °C and an average of 33.6 °C according to the palette of temperature of the thermographic camera, which ranged from 27.5 °C to 36 °C.

The following two images (Fig. 5) are thermal images of the same user of the bottle, the first of which was obtained before opening Bottle 2 with temperatures registered at: 34.5 °C Maximum; 30.8 °C Minimum; and an average of 33.1 °C. The second image shows temperatures of 34.5 °C—maximum, minimum of 31.7 °C and an average of 33.2 °C after Bottle 2 was opened.

Thus, the Wilcoxon Signed Ranks test was used to check the temperature difference of the moments of opening Bottles 1 and 2 ($p < 0.05$).

In the second stage, the calculation was made of the average differences between the thermal images before (MED1A) and after (MED1D) of Bottle 1, the final result of which was 0.003 ($p < 0.05$). In the third stage, the difference between the averages of the maximum values found in the thermal images of Bottle 1 were calculated before (MAX1A) and after (MAX1D) of the opening, the final result obtained being 0.010 ($p < 0.05$). In the fourth stage, what was calculated was the difference between the average of the minimum values before (MIN1A) and after (MIN1D) opening Bottle 1, a nonsignificant result of 0.059 ($p > 0.05$) being obtained.

So, first, we calculated the difference of the maximum values between the thermal images before (MAX2A) and after (MAX2D) of Bottle 2, the end result of which was 0.235 ($p > 0.05$). In the second phase, we calculated the difference of the minimum values found in the thermal images of Bottle 2 before (MIN2D) and after (MIN2A) of the opening, with the end result of 0.240 ($p > 0.05$). In the fourth phase, what was calculated was the difference of the averages of the moments before (MED2A) and after (MED2D) opening Bottle 2, thereby obtaining a result of 0.084 ($p > 0.05$).

**Analysis of the results of the experiment with Thermography**

As explained above, we emphasize that although the pilot study has indicated that there was no significant difference in the thermal images of the region of the face of the volunteers, this procedure was maintained to check the result with the other participants. However, just as before, it was not possible to analyze the metabolic reactions of the facial region of the real study. Instead, the images of the dominant palmar face of the volunteers presented a temperature difference. Because of this, there was a change in the experiment: instead of analyzing the face of the ind-viduals, the surfaces of the palms of their hands were analyzed.

According to the Wilcoxon Signed Ranks test, the difference in the averages of the test with Bottle 1 when compared with those of Bottle 2 showed significance because these were at a level of 0.004, when $p < 0.05$.

The average temperature of the palm of the hand of the Bottle 1 test showed a significant difference in the moments before and after opening with a significance of 0.003, when $p < 0.05$. This result confirmed the increase in radiated heat in the palm of the hands of the participants.

The average temperature of the hand that opened Bottle 2 temperature did not show a significant difference (Sig. 0.084) and $p < 0.05$. In this case there was no change inn heat radiated by the hand of volunteers.

Therefore, it is possible to verify that Bottle 1 generated greater metabolic activity and average of temperature increase (0.318) in the palmar region compared to Bottle 2 (0.073).

Havenith et al. [6] state that skin temperature depends on the amount of heat that reaches it. Additionally, [7] stated that the amount of body heat is continuously transferred by conduction (fourth form of heat dissipation) by the direct difference in heat between molecules. Bandeira et al. [8] add that the heat transfer increases in accordance with the increase in blood flow of the peripheral tissues.

Thus, greater or lesser irrigation of the tissues is an indicator of variation in local temperature that can be perceived using tenths of a degree of centigrade per square millimeter area of tissue [9], which in this case was observed the images of the palmar face.

Thus, the increase in the flow of blood to peripheral tissues of the palmar region in contact with the top of the bottle possibly prompted the increase in the temperature and the increase in the metabolic activity of the hand area which had greatest contact.

Moreover, the application of muscle strength and compression of anatomical structures, at the moment that the bottle top was opened, may have caused the transfer of heat to the areas of the hand that suffered greatest contact with the Bottle by friction. This small temperature gradient can be observed by analyzing the thermographic images obtained.

According to [5], the increase in the application of manual biomechanical forces in the process of opening screw caps causes discomfort and may limit the application of forces by users. That is, the user's perception of difficulty is inversely proportional to the ability to apply forces on the bottles. This reasoning will guide the analysis that follows.

Bottle 1 of our study showed higher heat radiated by the hand (metabolic activity) and higher temperature may possibly lead to less comfort by increasing the muscular effort used and the greater difficulty in using it. Thus, the user may feel less satisfied as to the use of this bottle.

As to Bottle 2, this generated less heat radiated by the hand (metabolic activity) and a lower temperature. Therefore, probably this bottle may have provided greater comfort because less muscular effort was used and it was less difficult to use. Thus, the user may have felt more satisfied when handling it.

To complement this analysis we corroborate with the study of [5] when they say that the discomfort in handling bottles can cause negative feelings such as pain, pressure, hardening and irritation. On the other hand, opening the bottle comfortably can provide a feeling of "a pleasant state of physiological, psychological and physical harmony between a human being and the environment…" which in this case occurs in the user-product interaction [10].

In consideration of the aspects of the design of the interface, the presence of textures and grooves of the bottle allow increased friction and improve the ability to apply forces due to friction [11, 12]. In this context, the tops of Bottles 1 and 2 have grooves on the surface so as to improve the application of torsional force. However, the considerations remain of the difficulties of use reported above.

## 5 Conclusions

Despite the innovation of the use of the thermography technique applied in usability evaluation, this proved to be efficient because it managed to meet the objective of identifying metabolic changes in the thermal images of the users of soft drinks bottles.

On the other hand, it was not possible to identify emotional expressions that were related to the process of user satisfaction. We believe that the emotional stimulus caused to the user during the activity was not enough to be expressed at the facial level and still be detected by the tool. Based on the studies described in this article, the experiments that were referenced indicated that the individuals were subjected to more intense stimuli while performing tasks: for example, fear, joy, thinking about how the task would be done. Unlike the level of stimulus obtained during the activity of opening the top of a bottle.

The results indicated that Bottle 1 was the one that produced the higher metabolic activity to the users' hands. Therefore, we believe that the increase in the metabolic rate may possibly be associated with decreased satisfaction.

Thus, the use of Bottle 2 possibly caused greater satisfaction to the user on account of the lower radiated heat (metabolic activity) in the palmar region of the users. Thus the activity of opening this bottle may be associated with using less muscular effort as compared with that of Bottle 1.

Another interesting point is related to the experimental situation developed by the authors Silva et al. [5]. In this study the user's experience when opening the bottle was different because the top of the bottle is designed not to break the seal. That is, users could not open the bottle that contained the gasified liquid. Thus, it was not possible to make comparisons because of the incompatibility of objectives of the experimental situation.

Conversely, the goal of our research was to analyze the perceived difficulty of users while performing the actual task and to compare this with the felt experience that may or may not have been satisfactory.

The findings were obtained arising from the two hypotheses that underpinned this research study. The first put forward the possibility that "The experience reported by the users of the soft drink PET bottles can be analyzed by means of the score for satisfaction obtained from the Likert scale (usability assessment) and compared with the experiences felt by the users (eye tracking and EEG)".

Given this hypothesis, the field study of usability evaluation succeeded in proving that it is possible to analyze the experience reported by users. Likewise, it was also possible to analyze the experience felt by the user on using Thermography technique, which was compared with the usability evaluation. Thus, this hypothesis was confirmed.

The second hypothesis stated that "The results obtained by the thermography techniques are effective for measuring the satisfaction (felt experience) of the users of the soft drinks PET bottles".

In thermography, what is explored is the perception, the ability to interpret and express the feelings of the individuals. In our study, we were able, by measuring the temperature of the thermal images, to associate the results with the experience felt at the moment of user interaction with the product. The efficiency of this tool at identifying the experience felt by the user was obtained by identifying the radiant heat in the palms of the hands (metabolic changes) of the thermal images in real time of manipulating soft drinks bottles. This also confirms our hypothesis that this tool is suitable for measuring the experience felt by the user.

Thus, the tools used confirmed the hypotheses that (1) the reported experience can be compared to the experience that the user felt and (2) that the tools used are appropriate to measure the experience felt and consequent satisfaction of the user.

Attention should be drawn to the fact that the Usability Field Study presented a result that is contrary to other studies. In this field study, volunteers said they liked PET bottle 1 best, while in other field studies, PET bottle 2 was chosen.

These results may suggest that the opinion reported by the user at the time of a usability evaluation by using a questionnaire, can be totally different from his/her thoughts/feelings or impressions regarding the use of a product.

Therefore, what our brain perceives and remembers may be different from the things that we say we understand and record when we are asked about this [13]. Thus, it is extremely important to use techniques that can compare the experience felt and the experience reported by the user. Another point of interest is that users can carry out correlations with their own unconscious processes with the meaning of their answers, the reasons for their preferences, their beliefs, and the analysis of their experiences [14].

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# Size Effects and Scale Effects on the Usability of Tablets in Finger Pointing and Dragging Tasks

**Chih-Chun Lai and Lung-Wen Kuo**

**Abstract** By comparing the operation times for the prevalent touch-input methods of 5 different display sizes in 4 applied tasks, this study examined the size effects and its interactions with movement scale effects in tablet PCs with the target sizes (*W*) and distance (*A*) proportionally increased (with a constant index of difficulty). Overall, task types (complexity) and the display sizes had significant effects and interactions. The 7″ display tasks underperformed the 9″–11″ displays (significantly in almost all the tasks except marginally significantly in the complex pointing tasks when compared to the 9″ and 10″ displays) and the 8″ display (significantly in the dragging tasks). Nevertheless, the increased distances and widths only result in non-significantly decreased operating times for increased display sizes from 8″ to 11″ in almost all the tasks. The motor scale effects seem to attenuate the size effects more profoundly in complex task types than in simple ones.

**Keywords** Task type · Size effect · Scale effect

## 1 Introduction

In various task types (complexity) applied, the size effects influence productivity, portability and user experience on different form factors of mobile devices, especially tablet PCs. Actually, there have been a great deal of competitive device convergence among display sizes. Since 2012, 10-in. table PCs have been deemed

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as the standard size; while manufacturers began launching larger and smaller sizes to erode the markets of Notebook PCs and Smartphones. No matter the tablet PCs operated with indirect or direct input devices, consumers required both portability and productivity; apparently, it was important to optimize display size and object scale for the tablet PCs as mobile devices.

## 2 Literature Review

An early experiment [1] indicated that the mouse cursor moved faster on larger display with constant "task difficulty [2]". It seemed that participants responded care-freely in using the larger display to move the cursor more rapidly than on the smaller display. The authors proposed that the impact of display size might be acknowledged as a cognitive effect that surpassed the considerable impact of task difficulty. The results revealed the effects of target size (*W*), *ID*, motor scale, and display size and its interaction with task type on the positioning time.

Studied on tablet pointing tasks using styli, Oehl et al. [3] also observed the significant effect of display size and its interaction with task difficulty in a multi-directional serial tapping task. With the 3.94″, 7.86″, and 11.72″ display sizes, the pointing times decreased from the smaller display to the larger display in the lower *ID* (2.58 bits) condition, while the error rates did not differ significantly. Both the pointing times and error rates decreased from the smaller display to the larger display in the higher *ID* (3.46 bits) condition.

With the same experimental method, another study [4] further investigated the age-related differences in the discrete and serial pointing tasks operated by the young and middle-aged adults. The results showed that the serial tasks were significantly faster than the discrete tasks. The pointing times were significantly lesser for the medium and large display than for the small display, while non-significantly lesser for the large than for the medium display. There was no interaction observed. However, any effect of age and display size reduced in pointing times (but not in error rates) when accounted for the moderating effects of aiming duration in the covariate analysis. The authors demonstrated that display size (task-irrelevant) and *ID* (task relevant visual information) affected tablet pointing performances with pen. Nevertheless, the above results attained at different distance-width pairs of identical values for *ID*s so as to cause some possible confounding conditions as mentioned in the research regarding the consistency in the design of Fitts' law experiments [5].

Some studies found the effects of visual variances, including target size (*W*), amplitude (*A*) and scale on movement time (index of difficulty $ID = \log_2 (A/W + 1)$, movement time $T = a + b \log_2 (A/W + 1)$ [2, 6]), and the target size has more powerful effects than target amplitude (*A*): Given the targets in widths (*W*s) and amplitudes (*A*s) were proportionally smaller (larger), the movement time would be disproportionally longer (shorter) (e.g., [7–10]). Although the *ID* remained the same but the scale effect with varied amplitudes (*A*s) and target's widths (*W*s) would reflect in different *a* and *b* on movement times. However, there was no study examined the possible interactions of the display size effects with visual variances.

From the literature review of the studies for movement times (*MT*), it was demonstrated that the effects of *ID*, target size and amplitude (and scaling), task type (task complexity and input device), motor scale, and display size, and the possible interactions of these factors should be considered. Still, the experimental evidence of the size and scale effects and their interactions with other factors on finger input tasks is few. Thus, this study investigated these effects and interactions revealed the efficacy in tapping and dragging tasks for different-sized tablets.

# 3 Materials and Methods

## *3.1 Participants*

The participants included thirty college and graduate students (18 female) from Tatung University in Taipei City. They were 20–27 years old (M = 23.6; SD = 2.25). All of them had extensive experience in using tablet PCs. All participants' dominant hands were right hands. All of them were unpaid and not aware of the purpose of the study.

## *3.2 Apparatus*

According to our pre-study of the tablet PCs existed in the market, ASUS Transformer Book Flip TP300LD (Intel® Core™ i5 4210U, Windows 8.1) equipped with 13.3″ screens diagonal (16:9 HD, resolution: 1366 × 768, Pixel density (PPI): 118) was used to display 7″, 8″, 9″, 10″, and 11″ screens diagonal, respectively. Unity 3D was used to make the tasks and measuring interfaces. The 5-sized displays were formed by proportionally changing the relative dimensions of active touch area and inactive frame area. The dimensions of the tested displays, pixels, and target size (widths) and amplitudes are listed in Table 1. The general interfaces of the software referred the Android interface. The recording software was written to record the process of the tasks and operating times.

## *3.3 Task Design*

There were three tapping tasks (Tasks 1, 2, and 4) and a dragging task (Task 3) tested in this study. To explore the effect of the factor task type, Tasks 1 and 3 were designed to be simple tasks and Tasks 2 and 4 were designed to be complex tasks in

**Table 1** Dimensions of the five touchscreen displays

| Display model | Active touchscreen diagonal (inch) | Display size of active area (W × D mm) | Scaling of target size (%) | Target size (mm) | Target amplitude (mm) | Target size (pixel) | Target amplitude (mm) |
|---|---|---|---|---|---|---|---|
| D7 | 7 | 94 × 151 | 100 | 6.0 | 28.7 | 28 | 133 |
| D8 | 8 | 108 × 172 | 114 | 6.9 | 32.8 | 32 | 152 |
| D9 | 9 | 121 × 194 | 129 | 7.7 | 36.9 | 36 | 171 |
| D10 | 10 | 135 × 215 | 143 | 8.6 | 40.9 | 40 | 190 |
| D11 | 11 | 148 × 237 | 157 | 9.5 | 45.0 | 44 | 209 |

terms of required cognition and motor movements. Tasks 1–4 were designed to imitate interfaces in the real world, the locations of point-and-tap targets were designed to be either pre-cued (known) or non-pre-cued (not known) to the user before visually identifying it. This study followed Annex B in the ISO 9241-9 standard [11, 12] to design the purposes, patterns, and steps of the tasks. The task types (patterns) and purposes of tasks were summarized in Table 2. The testing screen displays and processes were presented as Figs. 1, 2, 3.

**Table 2** Details of task types (patterns) and purposes of tasks are indicated as follows

| Tasks | Description of design and purposes |
|---|---|
| **Task 1**<br>Multi-direction pointing and tapping with consecutive targets<br>(task type: select and tap) | 1. With ISO 9241-9 multi-direction pointing and tapping assessment, it is simplified to locate each target icon in eight directions (0º, 45º, 90º, 135º, 180º, 225º, 270º, and 315º) relative to the center-located icon<br>2. The whole task 1 includes all the directions of tapping targets and successively presents targets clockwise starting at 0º to the right (one at a time) |
| **Task 2**<br>Multi-direction pointing and tapping with random targets (task type: select and tap) | 3. The whole task 2 includes all the directions of tapping targets and the target icons presents randomly in one of the eight different directions<br>4. According to the most common applications investigated in our lab's previous study, users proceeded with pointing and tapping at the graphic user interface (GUIs) to interact with selecting targets such as icons, menus, or hyperlinks<br>5. To imitate these the above mentioned usage situations, the selections of the centre icon are both pre-cued in tasks 1 and 2, while the selections of target icons surrounding the centre icon are pre-cued (presented clockwise) in task 1 but non-pre-cued (presented in random order) in task 2 |
| **Task 3**<br>Multi-direction dragging and dropping (task type: select and drag) | 1. According to our lab's previous study, users proceeded with dragging and dropping at the GUIs to move targets such as photos, files, or texts<br>2. To imitate the above mentioned usage situations, in task 3, the selections of the eight target icons are non-pre-cued but the centrally located "recycle bin" icon is pre-cued |
| **Task 4**<br>Successive selecting and tapping (task type: select and tap) | 1. According to our lab's previous study, the most common software applications consisted of pull-down menus for frequently used basic control<br>2. To imitate the above-mentioned usage situation (traversing multi-layered menus), all the target icons appear (in black, one at a time) from the upper-left towards the lower-right corner<br>3. All the target icons are non-pre-cued but the subsequent icon appears once the previous one has been tapped |

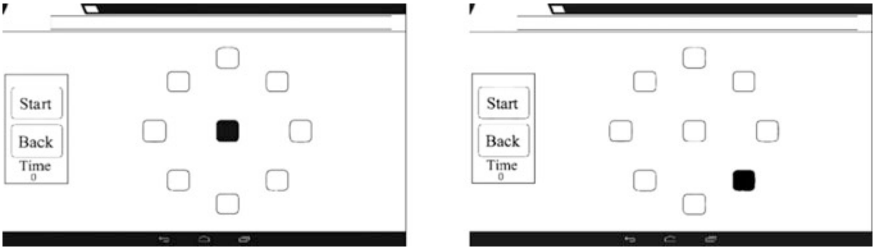


**Fig. 1** Testing screen display for tasks 1 and 2. (*Left* the 1st step—tap the centre-located icon (presented in black.) After the centre-located icon has been tapped and its color changes from black to white, the target icon simultaneously presents by changing its color from white to black. *Right* the 2nd step—tap the target icon (in black) and its color immediately changes from black to white to complete one trial, and a new trial presents simultaneously with the centre-located icon changing its color from white to black.) Conduct the tests 8 times in different directions as one set of task operations and finish 3 sets for each task (i.e., 8 repetitions × 3 sets = 24 trials.)

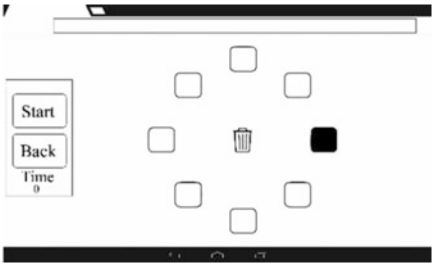


**Fig. 2** Testing screen display for task 3. Tap one of the eight target icons (its color immediately changes from white to black) in the 8 different directions (same as those of task 1.) Then drag it to the centrally located "Recycle Bin" icon and drop it (by lifting off the target icon and the target disappeared) to complete one trial. Subsequently drag and drop another one of the remaining target icons until all the target icons disappear. Conduct the tests 8 times in different directions as one set of task operations and finish 3 sets for each task (i.e., 8 repetitions × 3 sets = 24 trials.)

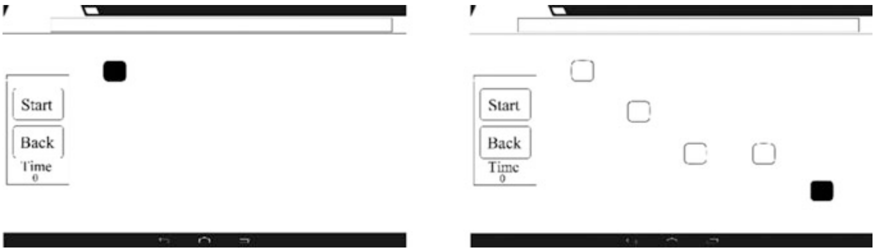


**Fig. 3** Testing screen display for task 4. (*Left* the 1st step—tap the target 1 and its color changes from black to white, and the next target (target 2) simultaneously appears in back. *Right* the 5th step—the following successive steps of the tasks were to tap from the target 2 to the target 5 in sequence.) Conduct the tests 5 times as one set of tests and finish 3 sets for each task (i.e., 5 repetitions × 3 sets = 15 trials.)

The *ID* was kept constant (2.53 bits) across all conditions by proportionally changing the target amplitudes and widths to investigate if the manipulated amplitudes and widths would affect the results. In this sense, for comparability, the size of the icons displayed in the 7″ tasks were set to the same value as our previous studies (i.e., 6 × 6 mm) and grayscale [13, 14]. The scale (screen diagonal length) of the active area proportionally enlarged, the distances (*D*s) and widths (*W*s) of the tasks were proportionally extended with the same percentages as their screen diagonal lengths compared to that of the 7″ display (see Table 1). All the distances (i.e., amplitude, *A*s) were the same on each display size condition.

## 3.4 Experimental Design and Analysis

There were three independent variables measured in the first portion of the experiment: the display size (a within-group independent variable) and the task type and gender (two between-group independent variables). As for the second portion of the experiment, there were three items (operational easiness, comfort, and preference) measured by subjective evaluation questionnaires. The items and gender were between-group independent variables and display sizes was a within-group independent variable. The operating time (i.e., task completion times) and process of the task were recorded after the recording software had been started. After finished a set of experiments, every participant immediately filled in a subjective assessment (Likert Nine-point Scale) with bipolar adjectives for operational easiness, comfortable level, and preference level of their pointing performances: (1) Difficult—Easy to apply, (2) Not comfortable—Comfortable, (3) Dislike—Like.

Dependent measures included operating times and the evaluations of the three items. Error rate was not measured in this study due to the error rates in our lab's other researches regarding similar tasks types with ID less than 3 [13–17] did not present any significant effect. Some other researches (e.g., for tapping and dragging tasks with finger see [18], for pointing tasks with mouse see [1]) have also revealed no significant effect on error rate under their experimental conditions.

A three-way mixed effects RM-ANOVA with task type (4 levels) and gender (2 levels) as between-group independent factors and display size (5 levels) as within-group independent factor was performed for operating times. Another three-way mixed effect ANOVA with gender (2 levels) and item (3 levels) as between-group factors and display size (5 levels) as a within-subjects factor was performed for subjective rating scores. Significant overall F tests were followed by Bonferroni post hoc contrast tests with adjustment for $\alpha = 0.006$ (=0.05/9) to account for the comparisons between variables with significant interactions of main effects.

## 4 Results and Discussion

For the operating times, RM-ANOVAs presented significant main effects of the factors task type ($F_{3,112} = 235.508$, $p < 0.001$, $\eta_p^2 = 0.863$) and display size ($F_{4,448} = 45.922$, $p < 0.001$, $\eta_p^2 = 0.291$), and a significant interaction between the two factors ($F_{12,448} = 2.812$, $p < 0.001$, $\eta_p^2 = 0.070$). In comparing the operating times for each the 5 display sizes and 4 tasks, the results of Bonferroni-corrected contrast showed significant simple main effects of the task type (7″: $F_{3,116} = 263.860$; 8″: $F_{3,116} = 124.624$; 9″: $F_{3,116} = 206.520$; 10″: $F_{3,116} = 204.787$; 11″: $F_{3,116} = 154.676$; all $p$′s < 0.001, $\eta_p^2 > 0.138$) and display size (Task 1: $F_{4,116} = 11.708$; Task 2: $F_{4,116} = 9.968$; Task 3: $F_{4,116} = 26.927$; Task 4: $F_{4,116} = 9.363$; all $p$′s < 0.001, $\eta_p^2 > 0.138$). Main effect of the factor gender was not significant ($F_{1,112} = 0.977$, $p > 0.05$, $\eta_p^2 = 0.009$). Other interactions were not observed (all $p$′s > 0.4). As shown in Table 3, the mean operating times of the 11″ (largest) display and 7″ (smallest) display were the lowest and highest respectively for all the tasks.

The operating times revealed that smaller displays underperformed the larger displays. This phenomenon confirmed the results of previous studies (e.g., [3, 14]). Moreover, there was another phenomenon: The different distance/width combinations with the same *ID* still resulted in the different movement times, which was also consistent with previous studies (e.g., [19, 8]). Nevertheless, as compared to the results showed in our previous study [14] without scaling of target sizes, the proportional scaling of target sizes seemed not to aggravate (or attenuate) the display size effect on the operating times.

Furthermore, the post hoc pairwise comparisons indicated that the differences were not significant (all $p$′s > 0.006) in the operating times for almost all the tasks among the 8″, 9″, 10″, and 11″ displays, except the performances in Task 3 for the 10″ and 11″ displays: They were significantly faster than the 8″ display (both $p$′s < 0.006). The reason might be that the display sizes (or net display size effects) of the 8″, 9″, 10″, or 11″ displays were not largely different from each other. In addition, the target sizes (widths) on the 8″ and larger displays (ranged from 6.9 to 9.5 mm) in this study were just close to those for touchscreen objects (7–10 mm) recommended by the Android UI guidelines [20] and those (7–9 mm) by "Guidelines for targeting" [21];

As for the above two exceptions, it might be because there was less hindrance (from the cognition and motor submovements requirements) of Task 3, the least complex dragging tasks, to induce more display size effects (especially induced by the larger size discrepancies between the 8″ and 10″ and between the 8″ and 11″ displays) than the tapping tasks did.

This phenomenon of the non-significant difference between the 8″ and the larger displays in the pointing performances was similar to the result showed in the recent study of Oehl and Sutter [4] that the difference between pointing times on the medium (7.86″, close to 8″) and large (11.72″) display was not significant.

**Table 3** Mean operating times (second) in the 4 tasks on the 5-sized displays (standard deviations in parentheses)

| Factor | Operating time | | | | |
|---|---|---|---|---|---|
| | All tasks | Task 1 | Task 2 | Tasks 3 | Task 4 |
| | Pointing and dragging tasks | Multi-direction pointing and tapping with consecutive targets | Multi-direction pointing and tapping with random targets | Multi-direction drop and drop tasks | Successive selecting and tapping |
| | Mean (SD) | Mean (SD) | Mean (SD) | Mean (SD) | Mean (SD) |
| Display size | | | | | |
| Variables | | | | | |
| 7″ (D7) | 13.43 (6.36) | 18.03 (2.20) | 20.19 (2.03) | 9.83 (3.34) | 5.69 (1.02) |
| 8″ (D8) | 12.00 (6.46) | 16.37 (5.19) | 18.63 (2.31) | 7.70 (2.52) | 5.30 (1.40) |
| 9″ (D9) | 11.44 (6.17) | 15.35 (3.64) | 18.49 (2.15) | 7.02 (2.54) | 4.90 (0.55) |
| 10″ (D10) | 11.14 (6.19) | 14.89 (3.68) | 18.37 (2.17) | 6.51 (2.55) | 4.81 (0.48) |
| 11″ (D11) | 10.86 (6.08) | 14.46 (3.77) | 17.77 (2.68) | 6.39 (2.95) | 4.81 (0.48) |
| Effects | Main effects | Simple main effects | Simple main effects | Simple main effects | Simple main effects |
| *F* | $F_{4,448} = 45.922$ | $F_{4,116} = 11708$ | $F_{4,116} = 9.968$ | $F_{4,116} = 26.927$ | $F_{4,116} = 9.363$ |
| *p-Value* | 0.000*** | 0.000*** | 0.000*** | 0.000*** | 0.000*** |
| $\eta_p^2$ | 0.291 | 0.288 | 0.256 | 0.481 | 0.244 |
| *post hoc* | D7 > D8<br>D7 > D11 | D7 > D9 | D7 > D9 | D7 > D8<br>D7 > D11 | D7 > D9 |
| | D7 > D9<br>D8 > D10 | D7 > D10 | D7 > D10 | D7 > D9<br>D8 > D10 | D7 > D10 |
| | D7 > D10<br>D8 > D11 | D7 > D11 | D7 > D11 | D7 > D10<br>D8 > D11 | D7 > D11 |
| Gender | | | | | |
| Variables | | | | | |
| Male | 11.53 (.33) | 15.24 (.94) | 18.26 (.52) | 7.40 (.73) | 120.32 (9.19) |
| Female | 11.94 (.27) | 16.21 (.76) | 18.98 (.42) | 7.55 (.59) | 109.00 (7.50) |

*$p < 0.05$
**$p < 0.006$
***$p < 0.001$

In addition, the differences were significant in almost all the tasks between the 7″ and each of the 9″–11″ displays (all $p$'s < 0.006), except for the marginally significant differences between the 7″ and 9″ ($p$'s = 0.009) and between the 7″ and 10″ displays ($p$'s = 0.008) in Task 2. The reason might be because of the large discrepancies of the reduced display size (induced intense display size effect) of the 7″ display. For the above two exceptions, it might be because there was more hindrance (from the cognition and motor submovements requirements) of Task 2, the most complex task, to induce lesser display size effects on performance differences (especially induced by the smaller size discrepancies between the 7″ and 9″ and between the 7″ and 10″ displays). This result consisted the results of our previous study [14] because the size of the 9″ display were close to the 8.9″ display. Obviously, it seemed that the reduced size of the 7″ display aggravated the display size effects.

As for the RM-ANOVAs on the subjective assessments, the results showed significant and marginally significant main effects of the factors display size ($F_{4,336} = 82.280$, $p < 0.001$) and gender ($F_{1,84} = 9.001$, $p = 0.004$), respectively, and no significant interaction. The significant main effect of display size supports the objective performances.

In comparing each scores for the three items, on one hand, there was no significant difference between the 7″ and 8″, between the 7″ and 9″ displays, or between the 11″ and 10″ displays in all the scores; nor was between the 8″ and 9″ displays in the operational easiness. On the other hand, all the scores for the 10″ and 11″ displays were significantly higher than the scores for the 7″–9″ displays although there was no significant difference among the operating times for the 8″–11″ displays in almost all the tasks. This phenomenon might be owing to the target sizes on the 10″ display and 11″ display were close to the optimal target size (9 mm) [20, 21].

Overall, the male participants scored marginally higher than the female participants did in the comfort level but only non-significantly higher in the operational easiness and preference levels. It might be because the male participants' fingers were larger than the female ones'. In this sense, the males might perceive the target distances shorter than the females did, although the males were only affected to perform non-significantly faster than the females did.

## 5 Conclusion

Although with a constant index of difficulty (2.53 bits), it seems that the closer the sizes of displays to those sizes of a generic laptops, the shorter the operation times. The results implied that the impact of target width was more important than that of the target distance, while the scaling (of target size) did not influence display size effect. Overall, task types and the display sizes had significant effects and interactions. Main effect of the factor gender was not significant. In addition, the motor scale effects seem to attenuate the size effects more profoundly in complex task types than in simple task types. On one hand, the differences were not significant in the operating times for almost all the tasks among the 8″, 9″, 10″, and 11″ displays, except for the significant differences between the 8″ display and each of the 10″ and 11″ displays. On the other hand, the differences were significant in almost all the tasks between the 7″ and each of the 9″–11″ displays, except for the marginally significant differences between the 7″ and 9″ and between the 7″ and 10″ displays in Task 2.

As for the subjective assessments, the rating scores increased from the smallest to the largest display. Genders and the display sizes had marginal and significant effects in all the tasks, respectively. There was no significant difference between the 7″ and 8″, between the 7″ and 9″ displays, or between the 11″ and 10″ displays in all the scores; nor was between the 8″ and 9″ displays in the operational easiness. Moreover, there were significant differences between each of the smaller (7″–9″) displays and each of the larger (10″ and 11″) displays in all scores (of operational easiness, comfort and preference levels) and between the 8″ and 9″ displays in comfort and preference levels. The male participants scored higher than the female participants did but only significantly in the comfort level. It might be because the male participants' fingers are bigger than the female ones. The males might perceive the target distances shorter than the females did. The results rationalized the phenomena that the 10″ ($\sim$9.8″) up to 11″ displays were popular in the tablet PC market and suggested that the object size should be larger than 6 × 6 mm for finger input.

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# Embedding Smart Materials into Products to Motivate the User: Flexers, a Smarter Approach to Finger Splinting

**Marco Ajovalasit, Massimo Micocci and Rob Adam**

**Abstract** Embedded intelligence is radically changing the way designers conceptualize and develop technological artifacts. The use of smart materials to design products are uncovering new ways to interact with users so as to engage, entertain and inform them, coding new languages of communication. This study investigates how Smart Materials could support the monitoring of the user's health condition in rehabilitation situations through an embedded input/output system, and how the occurring feedback could be perceived as unobtrusive, easy to understand and motivating. In this study, Flexers, an interactive finger splint is presented which includes adaptive and sensitive materials as a vehicle to achieve an intuitive interaction that promisingly shapes the occurring product experience with renewed engagement of the user. The results suggest that the use of smart materials combined with light based feedback could be used as a motivating tool for engaging the user in the rehabilitation activity.

**Keywords** Smart materials · User experience · Human centred design · Interaction design

## 1 Introduction

In the last decades material sciences have made technological advancements and discoveries that have radically changed the role consumer products have in everyday life [1–3]. As a result, technology is progressively more embedded in

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daily life, producing novel experiences that are enhancing the way the environment and the interaction with products support and entertain us. For example, the Waterradio[1] by Clemens Winkler combines the technical capacity of a sensor-actuator system on a wooden table with the aesthetic of the natural material to create a unique, new synthesis of surface intelligence. The surface becomes acoustically active when touching water accidentally spilling out of a glass; Christian Iten, Daniel Lüthi and Emanuel Zgraggen designed "Tangent—a multi-touch surface",[2] interactive multi-touch interface that can be used by a number of users at the same time to develop new intuitive forms of interaction; the Hug-Shirt™ by CuteCircuit[3] is the world's first Touch (Haptic) Telecommunication Device that virtually transmits and receives hugs.

In the realm of product design, materials play a fundamental role and they are selected for creating certain experiences and the associated meanings through their characteristics [4, 5]. Based on the view that products are enabler of a users' experience and not their focus, materials should nowadays be considered for their dynamic and responsive qualities (input-output), which could change their properties on demand and adapt to ever-changing user requirements without the need of further mediation/interface, e.g. peripheral devices for input or output.

The field of care and well-being has been identified by many researchers [6] not only a growth market where the applications of Smart Materials result beneficial to their users, but it is also an area where intuitive-to-use, attractive and non-stigmatizing products can make a real difference. For example, designing for ageing population requires more and more solutions that allow older adults to live independently [7], while people with eating disorders such as obesity, demands specific products to monitor their health and describing correct eating patterns. Example like Future Care Floor [8] shows an instrumental integration of the SMs materials into the home environment. This sensor floor seamless integrates piezoelectric sensors to support old and frail persons living independently at home. The purpose of this application is to detect abnormal behavioural patterns of the inhabitant and activate rescue procedures in case of falls or other emergency events. In this vision, all around matter should be responsive, adaptable and able to convey information without any additional level that could be perceived as intrusive by the user. A particular area of interest where Smart Materials interactions have been proven to be useful is in the field of rehabilitation and sports. For example products like "Radiate Athletics"[4] adopt thermochromic pigments to enrich sport garments with the ability to display the body area positively affected by the training performance; Mickael Boulay[5] designed "Measure less to feel more", a diabetes reader

[1]http://clemenswinkler.com/skin/?cat=7.

[2]http://www.designerssaturday.ch/?pageID=203&lng=en.

[3]http://cutecircuit.com/collections/the-hug-shirt/.

[4]http://www.radiateathletics.com/.

[5]http://mickaelboulay.fr/.

that reduce stress on user while measuring blood sugar level by creating an emotional and engaging experience through dynamic colour effects.

The context of investigation of this paper is grounded on the British Health and Safety Executive (HSE) reports, estimating 201,000 total cases of upper limb disorders of working people, which led to 3.2 million working days being lost in 2013/14 [9]. Musculoskeletal finger injuries is considered an emerging field of investigation where innovative design solutions can counteract the long recovery time, prevent further damages to the tendons and improve the overall experience. A tear to the tendon can take 12 weeks to recover to full strength and up to 6 months to regain a full range of motion [10]. This is a key problem, as patients do not intend to stop using their hands for normal daily activities, therefore potentially causing further damage.

Departing from most of the current literature on Smart Materials, the overarching goal of this paper was to explore how to improve the experience of a rehabilitation device designing a *smart interaction* between the user and the product through the application of Smart Materials. This approach in return would help the design community to conceptualize and realize immediate products that is those where the interaction is directly with the product without the intervention of additional interfaces. The potential benefit of this approach is to design technologies that are readily available to a wider inclusive audience, and people can focus on the task which they are involved without concentrating on their interaction with the mediating device. In light of the Human-Centred Design approach [11], this study is based on the assumption claims that Smart Materials can be adopted to simplify the product interactions; the user will therefore benefit from new communicative languages that designers are guided to shape though the dynamic and interactive properties of the Smart Materials. The aim of this paper was to investigate how dynamic materials could support the monitoring of the user's health condition in rehabilitation situations through an embedded input/output system, and how the occurring feedback could be perceived as unobtrusive, easy to understand and motivating for the user. The overarching objective of this work is to design an interactive hand rehabilitation device where sensitive and interactive materials embedded on and within the device could be able to detect changes in the human body and translate the acquired information into intuitive feedback. The ultimate user testing will demonstrate how the novel interaction designed guides the user through the recovery process of musculoskeletal problems. In this paper Flexers, an interactive finger splint, which has been designed by means of adaptive and sensitive materials, is presented as a vehicle to achieve an intuitive interaction that promisingly shapes the occurring product experience with renewed engagement of the user.

## 2 Smart Materials and Their Applications: State of the Art

"*Smart Materials*" (SMs) is a relatively new term for materials that have changeable properties and are able to reversibly alter their shape or color in response to physical and/or chemical influences, e.g. light, temperature or the application of an electric field [12]. The Knowledge Transfer Network defines SMs as "*materials that display smart behaviours*".[6] A smart behaviour occurs when a material can sense a stimulus from its environment and can react to it in a useful, reliable, reproducible and usually reversible manner. SMs also incorporate features such as sensors and actuators, which are either embedded within a structural material or else bonded to the surface of the material allowing control [13]; the control capabilities permit the behaviour of the material to respond to an external stimulus according to a prescribed functional relationship or control algorithm. This engineered ability brings materials to be applied not only for their physical substance, but also for a combination of input/output signals triggered. A large body of research has been published on the properties of SMs in the last decades as presented in Table 1. However, there is currently lack of a classification of the dynamic properties of the smart materials that can be used support and build the user experiences and novel interactions.

According to the existing literature, information to the users and type of stimuli to action can be delivered in different ways as follows:

- Augment the expressive and interactive potential of common materials such as in the studies [14–17];
- Create products that can act and respond without mechanical parts: [18];
- Create products that can act and respond autonomously to changing environmental condition [19, 20].

Designers and engineers are starting to deploy the properties of materials to enhance the experience unleashed by products and unlock design opportunities for creative applications. It is therefore reasonable to imagine that products with SMs embedded will not be designed only to improve a functional feature of the product, but mostly to afford and support a more meaningful and immediate interaction with the users.

[6]https://connect.innovateuk.org/web/smart-materials/smart-design.

**Table 1** Classification of smart materials (SMs)

| | Gandhi et al. [13] | Banks et al. [24] | Culshaw et al. [25] | Srinivasan et al. [26] | Addington et al. [14] | Ritter [12] |
|---|---|---|---|---|---|---|
| Electro-rheological fluids | *x* | *x* | | *x* | | |
| Piezoelectric materials | *x* | *x* | | | | |
| Shape-memory materials | *x* | *x* | | | | |
| Fiber-optic | *x* | *x* | | *x* | | |
| Electrostrictive elements | | *x* | | | | |
| Magnetostrictive fluids | | *x* | | | | |
| Sensing technology: physical measurement, chemical and biochemical sensing in structural assessment | | | *x* | | | |
| Actuator techniques: Piezolectric and Electrostrictive materials, magnetostrictive materials, shape memory alloys, electrorheological fluids, electromagnetic actuation | | | *x* | | | |
| Magnetorheological fluids | | | | *x* | | |
| Vibration absorber | | | | *x* | | |
| Biomimetic materials | | | | *x* | | |
| Property-changing materials: shape-changing materials, colour and optically changing materials, adhesion changing materials | | | | | *x* | *x* |
| Energy exchanging materials: light emitting materials, electricity—generating materials | | | | | *x* | *x* |
| Matter—exchanging materials | | | | | | *x* |

# 3 Methods

The investigation carried out in this work was based on the Human Centred Design approach [11] as a way of using experience to design better products. The method initially focused on existing products and then focused on capturing and understanding users' experiences so as to attune the product to their requirements. The method followed the following steps:

- benchmarking and product analysis on the available products on the market;
- Adopting the principles of gamification so as to define concept requirements for enhancing product engagement.
- Identification of representative concepts directions based on existing products;
- Contextual interviews with physiotherapists, occupational therapists and patients who had suffered from finger injuries to discuss the concepts identified and get novel directions on further developments.

## *3.1 Benchmark and Existing Finger Splinting Products*

Most finger splints can be split into four categories as shown in Fig. 1. The choice of which splint is used is dependent on the injury and the severity of it. Each type of splint has a different level of restriction, ranging from immobilisation of a single joint to the whole hand. Most splints tend to support the injured area statically but there are also dynamic versions available.

## *3.2 Gamification by Design*

By analysing the current patient experience, it is possible to identify how the recovery process could be enhanced through the integration of SMs and the gamification of the experience to keep patients engaged and adherent. Zichermann and Cunningham [21] define gamification as "The process of game-thinking and game mechanics to engage users and solve problems.". The gamification of a product is

**Fig. 1** Existing finger splinting products: **a** joint, **b** finger, **c** full finger, **d** full finger

not necessarily about turning it into a game, but using the elements of a game to change the way a human interacts and behaves when using a product to make it more engaging [22]. Three main aspects of gamification [21] were adopted to develop the device: motivating the user, through different levels of difficulty and providing feedback on progress; empowering the user, giving him all the tools and guidance they need to complete his objective; re-engaging the user, by creating a loop of engagement that encourage him to reiterate the interaction.

### 3.2.1 Motivating the User

Psychological motivations could be split into two main categories: intrinsic (internal) and extrinsic (external). It is possible to argue in a medical context that the personal desire to make yourself better is a bigger motivational factor than other people's views [21]. Because of this it is possible to look at Mark Lepper's design principles for intrinsic motivation and see how they can be used to encourage someone to help themselves. They include: giving the user some control of the activity and when they complete it; continually challenging a user through different levels of difficulty and providing feedback on progress. Providing a level of curiosity that encourages user to learn more about the process. Contextualising the process they are completing so they learn about what they are doing and why [23].

### 3.2.2 Empowering the User

A key part of gaming design is giving the player all the tools and guidance they need to complete their objective. The book Gamification by Design sums up this theory by using the metaphor of a Sherpa guiding a person up a mountain. "Be their sherpa. Give them the status, access, power, and tools to get them where they need to go. Do it right and they'll be yours forever" [21]. This means that you do not need to complete the task for the user, you just need to equip and encourage them to do it for themselves.

### 3.2.3 Re-engaging the User

If playing a game was a linear experience people would lose interest and stop playing, this is why games are built as a loop of engagement. Kumar splits into four key stages: "motivate emotion, call to action, reengage, feedback and reward" [22]. By creating a loop of engagement you encourage a user to interact and reward them for doing so, a form of positive reassurance and reinforcement.

### 3.3 Exploratory Investigation and Concept Refinement

The preliminary investigation led to a refined concept where both technical and experiential parameters where considered. Particular attention was given on the efficiency of the light signals and the understand ability of the whole interaction. Whilst currently there are a large number of static and dynamic finger splints available on the market, there isn't a portable splint or a device that allows the patient to dynamically monitor their own injury. As a result that means that there is a niche for this kind of product that is only possible due to current advances being made not only SMs, but the smarter implementation of them that make them more accessible and usable to potential users. Three concept directions were initially chosen, as shown in Fig. 2, each based around using light as a feedback method to the patient, but allowed for different levels of freedom of movement.

- *Fixed*—Improving traditional static splinting by using light based feedback as a stress indicator for when the user moves or tenses their fingers too much whilst wearing the splint.
- *Flex*—Using light based feedback to guide dynamic splinting, to provide the user with information regarding the controlled movement of the splint and highlighting when they are moving too much or too little.
- *Free*—A 'visual' splint that has no physical restriction, but instead guides the user only through light based feedback about when they should or not should be moving their finger.

Based on these three concept directions, a focus group with physiotherapists, occupational therapists and people who had suffered from finger injuries was performed with the intent to get direction of further design development. The experts in the focus group agreed on the design of a progressive splint that did not focus on one concept route but focused on adapting to the recovery process, allowing for more movement overtime guided by light, to help a patient recover quicker and better. The splint was divided into a main body and attachments to allow for interchangeable components. In the long term this would allow for a range of different attachments that allow for different ranges of movement that target specific joints. Figure 3 highlights the main areas of strain in the finger. The splint would work by having interchangeable components that would allow for a gradual progression of movement in the device; these components could also change the level of protection provided to the finger. This means that over the course of the recovery, the patient would be allowed to move their finger more and reduce the


**Fig. 2** Three design concept directions based on existing products

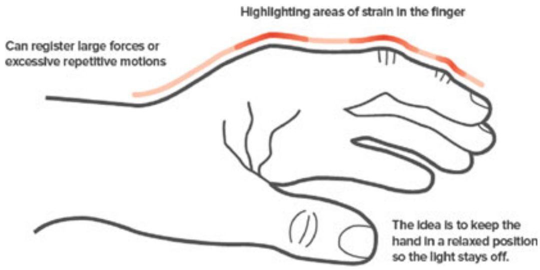


**Fig. 3** Highlighting areas of strain in the finger

size of the splint. Light based feedback would be used to provide warnings to the patient when they are using their finger too much as to be counterproductive to recovery.

In order to create a structured process for design development, it was decided to split the prototyping into the following different key design functions: electronics and user interface; splint main body; splint attachments and strap. This prioritised the most important functions into design synthesis hierarchy that would prove the functionality of the concept. Initial prototyping of the electronics was based around experimenting with different sensors to see how well they would work at recording finger movements. These including using ceramic piezos, PVDF films and flex sensors, the latter proved to be the most successful, as not only did they come in more usable sizes, they were still highly flexible and provided stable and usable data. The adoption of the Arduino board allowed the flex sensor to be attached to the glove and connected to a LED output; the basic interaction achieved was the control of the LED intensity based on the bending of the finger. The application light emitting and electricity generating materials appeared then promising both in terms of quality of output light and integration of the interface to a wearable device. Initially, electroluminescence panels seemed like the most suitable material for this, as they produce a homogenous light but it was found that they were tricky to work with and time consuming. So a switched was made to using flexible LED strips, which saved a lot of time as they are as easy to work with as normal LEDs with the only real drawback being the light is not homogenous. Figure 4 shows the LED strips and flex sensors embedded in initial prototype. After creating a number of this LED strip and flex sensor combination, they were then sewn onto a glove as to

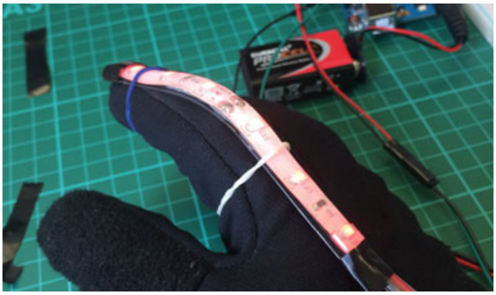

**Fig. 4** LED strips and flex sensors embedded in initial prototype

improve coding and create an experience prototype that replicated the desired light based warning to the wearer based of their finger movements.

## 3.4 User Testing

A user testing protocol was employed consisting of a set of interviews and prototype assessment with ten students (mean age 22 years) from Brunel University London with the aim to test the feasibility of using light based feedback as a rehabilitative aid on the dedicated “experience glove”, to understand how the users react to the light and finally test the shape of the ultimate plastic splint prototype on a range of different anthropometric size hands to optimise fit and comfort. The experience glove was a supplementary device able to create multiple light feedback aiming to understand people’s reaction to the light signals produced and how they will benefit the development of new interactive interfaces. The user test study required participants to wear the “experience glove” for a few minutes, as shown in Fig. 5, and answer two questions: What does the light-based feedback is telling you about your finger movements? Which of the colours presented do you think is the best indicator for dangerous finger movements?

After the implementation of the intended interaction, the main body of the splint was designed assessing his ergonomics and fit as shown in Fig. 6. Through a series of iterative prototypes it was possible to achieve a design that used a single main body and attachments that used living hinges allowing the finger to flex when worn as shown in Fig. 6. The moving splint attachment was tested against a to scale diagram of the theoretical maximum bend of the prototype. This was to check that it was actually capable of achieving the desired limit of 30° of movement at each knuckle. From checking the prototype against the diagram, the movement limit of 30° at each knuckle was near enough spot on. It was only 1° over at the second joint, though this was more likely due to the prototype quality rather than the design of the hinge at the joint.

**Fig. 5** User testing of the “experience glove”

**Fig. 6** Experience prototyping of the splint shape and dynamic attachments

## 4 Findings

From the initial user testing with the experience glove, it was clear that most participants presume that when the light gets brighter that the finger movement is not correct, with only one participant saying that it meant nothing. Having explained to them it was a warning, they were then asked which colour they thought was best at this; eight out of ten said the red was the best colour for this. The results found in this work on the assessment of the splint main would suggest that while the size of the splint main body and attachments were not correct for a number of the participants, the shape and fit of the wrap around the finger were comfortable and easy to put on. It was also found that the splint worked well on either hand, for the index, middle and ring finger. The results suggest that users were capable to understand that light based feedback was telling them that their finger movements were dangerous and that it is a warning. This study is the first step towards a structured investigation that aims to consider the technologies as adaptable to human needs and expectations. Through this approach the interactive parameters elicited by the materials work as a connection point between the product features and the user expectations. The possibility we have to shape and engineered, smart materials based on our requirements is a great opportunity designers should consider. Nonetheless, there is a strong need to systematically organize the potentialities of SMs in a method that designers can easily adopt. Working on materials has the primary benefit that every single object could be embedded with different dynamic properties. Matter is everywhere and that matter could be designed to be

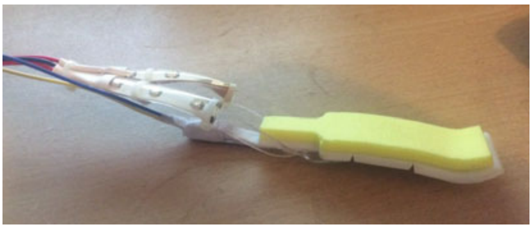

**Fig. 7** Work like prototype with integrated electronics

responsive, adaptable and able to convey different qualities of information. Responsive devices are, then, less invasive and have more possibilities to be socially accepted. The human body owns an undefined set of possibilities that Smart Materials can disclose and exploit for different purposes. The knowledge gained from creating the experience glove allowed for the creation of a works like prototype which took the prototyped dynamic splint design and integrated the electronics into the body as shown in Fig. 7. This helped integrating the light based feedback into the context of the design application by allowing the user to put on a finger splint that does allow the user to move his finger, but provides warnings when he does it too much.

## 5 Conclusions

This study provides a practical demonstration of the opportunities offered by SMs with the aim to investigate how new technology could be embedded to improve the performance of everyday products and how we experience them in a systematic way. Within this work, the use and application of SMs as mean of immediate interaction, have allowed to enhance with sensing and reacting capabilities a finger rehabilitation tool. The key to the success of SMs in this application is the perception of the interface as completely integrated in the device, as it was an "invisible" guide supporting the user. The study presented is a first step to empirically frame the value that SMs could have to produce unmediated experiences and overcome the barrier of traditional product interfaces in a finger rehabilitation tool. Further testing and development into how light based feedback could be used as a rehabilitative tool should be fully exploited. There is a lot of potential ground for experimenting with the application of the warning system to different supports and also different areas of the body. Also further development is needed to create a secondary layer of feedback to the user, by exploring interconnectivity with a smart phone to provide data about the recovery processes allowing for a user to monitor their actual progress.

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# Part III
# Human Factors in Design and Management

# Human-Automation Manufacturing Industry System: Current Trends and Practice

**Beata Mrugalska, Magdalena Wyrwicka and Barbara Zasada**

**Abstract** The paper deals with the problems of introduction of modern automated solutions in a big industrial company located in the Wielkopolska region in Poland. It shows the inevitable role of human factor in such systems and the effects when no enough attention is being focused on the design, installation, maintenance and other functions which are mainly done by the humans. In such systems there should be done a reasonable division of operational tasks between an operator and machine.

**Keywords** Automation · Human factor · Machine · Manufacturing process

## 1 Introduction

Recently, manufacturing industry has changed its focus from a supplier to customer-driven market. It leads to the competition between suppliers as a greater choice of products is available on the market. The customers are becoming more and more demanding but their commitment to staying with a particular product brand is decreasing. All these actions create the need for product innovation, low-cost customization and better service. In the consequence, the product life cycle is shorten, time-to-market and investment costs are reduced while maintaining the quality of products [1]. In order to adjust to all these changes the concepts of automation for supporting engineers can be applied [2].

The introduction of automation is supposed to increase system performance, flexibility and optimize utilization of resources [3]. However, the reliability and

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validation of such systems are often questioned [4]. It is required to explicitly consider job and task design as the appropriate level for interaction between human and machine influences the desired outcome in the production area [5, 6]. It is predominantly visible when the intervention has to be done at the margins of safety [7].

This paper regards the importance of recognition of human role in automated systems. It shows that regardless how advanced the system can be it is crucial to pay attention to all its elements and allocate tasks in relevance to it. The results of the investigations showed that humans cannot be eliminated from the processes in automated systems. Introducing such systems into industry requires that the management should foresee the need of their control, utilization and maintenance which have to be done with the engagement of employees.

## 2 Automation

Generally, automation is perceived as a very complex term in the manufacturing processes. It is defined as the "progressively transferring regulating and controlling functions from humans to technical systems" [8] which are based on mechanical, electrical and computer-based subsystems [5]. The essential task of automated system is to execute a great number of functions automatically, but in a reasonable manner referring to safety and rational use of resources [9, 10]. Thus, it is possible to differentiate up to 10 various levels of automation which focus on a different degree of an automated task from fully manual to completely computer automated [11]. In the taxonomy presented on Fig. 1 the interaction between humans and machines is explained on three basic levels.

As it can be noticed the degree of automation is strictly related to process operations. In a case of off-line operation a worker responsible for the operation does a job without an exchange of information with computer which is only used for a typical general-purpose tasks in an individual configuration. When automation system is in on-line work in the open loop it indicates that monitoring of the process is done by the personnel with the application of computer which provides information of the process in real time. However, the final result of this monitoring depends on the worker's experience and knowledge of operating procedures. When input, processing and output data are received automatically from separated sensors, it is called on-line closed-loop operation. Such level of automation requires high standards and it is not the most appropriate for making decision to crisis situations where a high level of unpredictability can appear. However, in the case of the quantified input data the methods of operations research from heuristic approach can be applied [9].

In the literature it is possible to differentiate several factors which should be recognized while decision-making about automation. The advantages of manual work over the automated one can be the following [14, 15]:

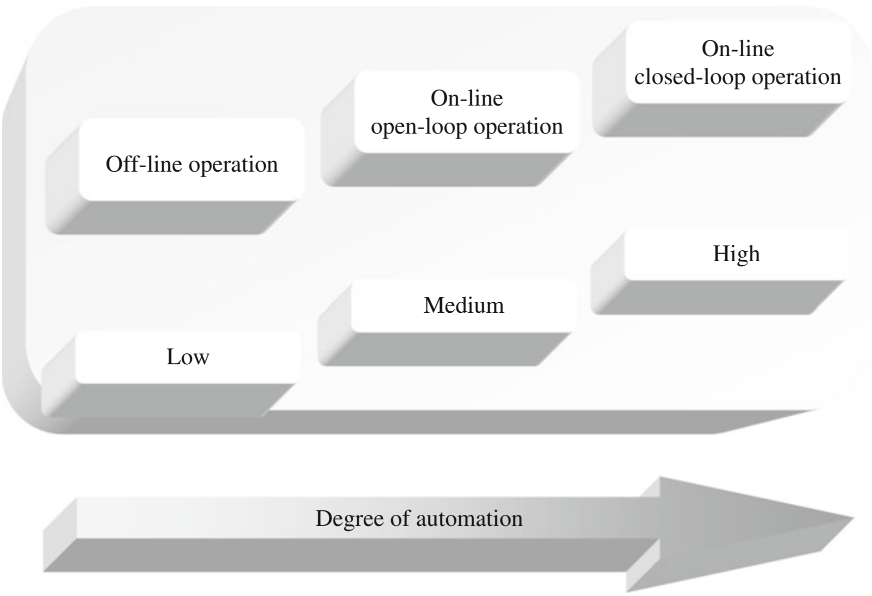


**Fig. 1** Automation and its process operations (adapted from [9, 12, 13])

- task is too technologically difficult to be automated (lack of ability to access to the work location or different adjustments as they require changeovers during the process, skillfulness and coordination),
- task concerns a short life cycle production (economically incorrect for the products being on the market for rather short period of time; easier to produce tooling for the production than an automation system),
- task regards production of customized products (a demand for exclusivity),
- constant changes in the demands of production output levels (the present capacity of the automated system is not enough for the output, and human labor must be integrated to the production system),
- a brand new product (manual work can avoid the loss of investments as the market is indeterminate).

On the other hand, automation is perceived to be to "recreate natural activities either for enjoyment or for productivity with less human effort and hazard" [16] as it allows to increase efficiency and reduce variability [17].

## 3 Human Role in Automated Systems

Humans play an evitable role in solving planned and unplanned problems in the production cycle. The advantages of them over machines are illustrated in Fig. 2.

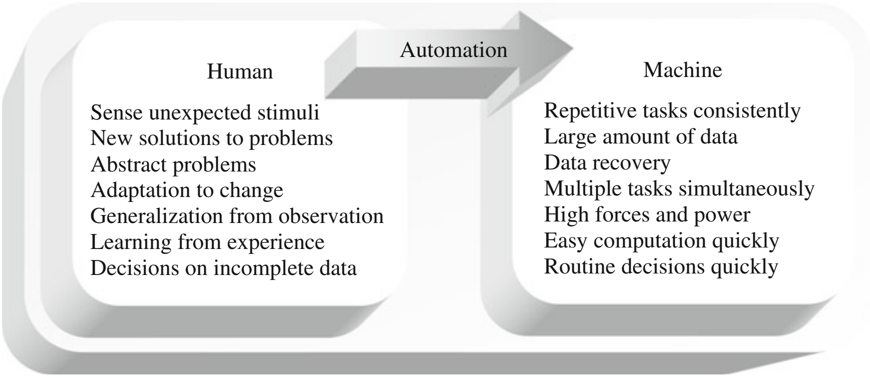


**Fig. 2** Humans or machines (adopted from [15])

As it can be seen there are some situations in the production systems where the human presence is still required and machines are not able to bridge this gap [18]. For example, in any system, regardless if it is automated or not, skilled workers are required to maintain and operate the equipment [19]. In order to upgrade software, equipment or design new tooling or projects the personnel is also needed. Without the staff, their knowledge and experience, it is not possible to run the business or plan the factory layout [15]. Therefore, the automated systems should be flexible to perform their function with the choice which can be done when the function raises. The decision should be reversible to enable to choose or not automatic features [20].

The automation leads to the situations where more and more often humans perform less physical work what leads to mental fatigue in the automation. In particularly, this problem concerns attending, remembering and basically thinking. On the other hand, as humans are removed from the process even temporally, it can be said that automation breaks the monotony related to repetitive work and boring operations. However, some workers cannot be satisfied from their role as supervisors and monitoring the process because they require more involved in the process. It can also happen that as the system is overtaken by the process the employees trust the system so much that they stop acting independently when it is needed. It is common that more trust is given to humans than machines even if automation might be more reliable. Both humans and machines make mistakes but only people can correct them. They are also stable in their behavior and express creativity performing any tasks [5].

Managing advanced systems it is worth to apply the principle of hierarchy between particular levels of organization and provide the exact level of automation. It is clearly visible in the case of higher levels of management, which are engaged in decision making, direction and control, the executive levels responsible for performing the decisions of higher level management and lower levels work on raw data [9]. The amount of data about the process decreases at higher levels of management. The raw data is converted on each level to achieve the more specific information content.

The allocation of functions in socio-technical systems should be done in relevance to the whole work system. Thus, tasks should not be performed only by human or machine and cooperative automation should be introduced as it allows to protect against unwanted automation effects [21]. It is advisable to design them in such a manner that they can be distributed between both of them with the interaction. In order to succeed, the human aspects should be taken into account from the start, in a development process as later there is less opportunity for correction of any imperfections in technology and organization [14, 22, 23]. Furthermore, two key characteristics of automation such as observability and directability have to be designed to see what is and will be performed in the future. As far as the choice of the level of automation and decision about allocation of tasks or functions are concern, their application mainly result from economic interests rather than human cognitive abilities. For example, if more efficient control provides more profit the automated technology will be implemented [14].

## 4 A Case Study

The illustrated situation concerns the problems of introduction of modern automated solutions in a big industrial company located in the Wielkopolska region in Poland. It was analyzed in 2014 when a board of the company decided to purchase a new machine in order to support the overloaded machinery. It was assumed that this new machine will be able to produce a large number of products and retooling will be faster. Moreover, it was supposed that modern solutions will be provided, even not used in this company and others. However, in practice it appeared that some components of the purchased machine were prototype solutions and not tested in the industry.

The purchased machine was provided to the company in the end of 2014 on the basis of the agreements between the manager of production without any engineers, mechanics or electricians and production company. This manager accepted all technical solutions introduced in this machine and was also responsible for its final delivery. All these activities had a great effect on the functionality and efficiency of the purchased machine.

After providing a machine to the company and its installing, the stage of trainings started. In the training a group of employees representing technical division was supposed to participate. However, in practice only one employee was able to come as the rest of them were needed to solve current production problems or do other tasks. Finally, it appeared that besides this employee only one mechanical engineer, who was present while the installation of the machine, was trained. The lack of knowledge about the purchased machine influences its operation until today. The company works in three shifts and only one person is able to retool the machine. The rest of the employees always emphasize that they were not

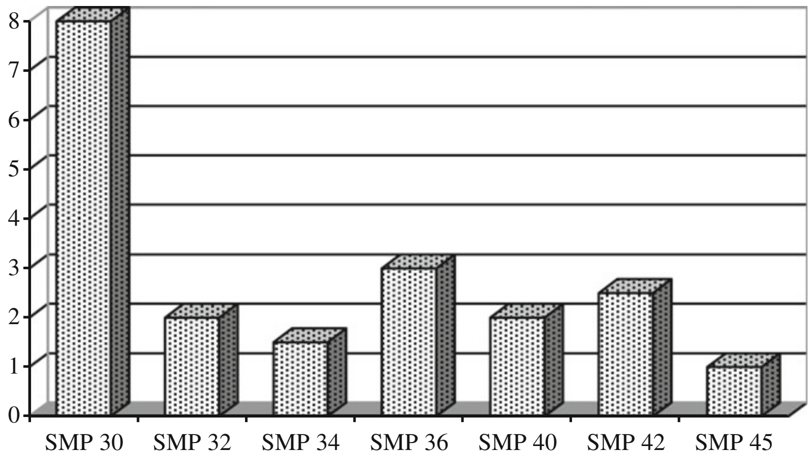


**Fig. 3** Average changeover duration on different machines in the company

trained and do not know how to do it. It is clearly visible that the workers are afraid of new solutions. Whenever technical problems are identified or a new production order is issued they prefer to look closer to other machines. In practice it makes difficult to plan and organize production processes and extends production lead time. Therefore, changeover also takes more time than it was assumed for this machine (SMP 30). The comparison of average changeover durations for selected machines is shown on Fig. 3.

These data concern changeovers for different size products and folding. It can be clearly visible that the longest time is needed for the operations performed on SMP 30. It results from the construction of the machine which requires changing a lot of parts and removing guards (it is very well covered and the access to many parts is difficult), and additional adjustment of the whole production line to provide products in accordance with quality standards. A diversity of products, that can be manufactured on this machine, also contributes to the prolonged changeovers. In this case it is possible to produce 15 product assortments whereas the average number is 6 in reference to size, folding and number of items. Such prolonged changeover lowers the index of accessibility and prevents short production series as they increase production cost. It should be also emphasized that all these 15 products represent only 70 % of the product range which was planned to be produced. The rest of the planned products cannot be manufactured because there is a lack of format parts for packaging equipment and appear technical disturbances which should be solved by the producer of the machine. The another planned visit is supposed to be held in April 2016.

The low index of accessibility to this machine (ca. 60 %) results from breakdowns that appear much more often than in other machines (ca. 5 %). As they result from the application of new solutions they often require contacts with the service. However, it should be emphasize that the cooperation with the service is very

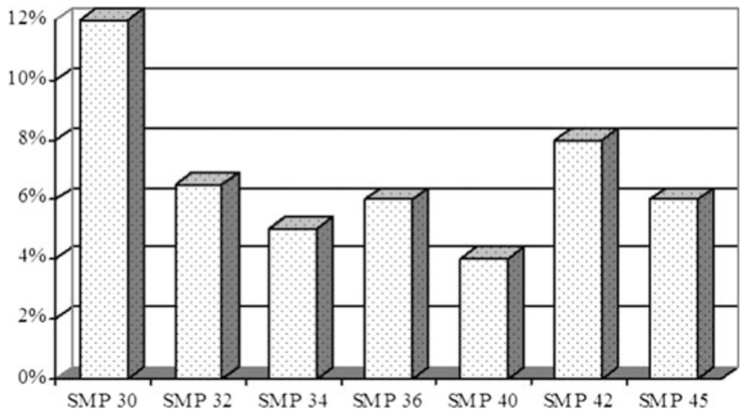


**Fig. 4** Average level of waste on different machines in the company

difficult. The service is often not available, they do not answer emails and phones in emergency situations. These situations increase duration of fault detection and period of time needed to obtain spare parts. It is worth to indicate that the cleaning of this machine is more time consuming as it is well covered and the guards have to be taken off. Moreover, there is a lack of the access to the parts which should be regularly cleaned to eliminate its negative influence on the production process.

All the mentioned problems also influence the waste which is obtained on this machine. For example, longer time of order adjustment results in additional production material usage which is a production waste. Therefore, the waste, which is generated at this machine, is greater than at other machines. These data are shown on Fig. 4.

In this case study it is also worth to pay attention to machine efficiency. Preliminarily, it was assumed that it would be from 42,000 to 51,000 pcs/h. In practice, it was necessary to reduce the machine speed due to technical and quality problems. Finally, its efficiency decreased up to 20,000 pcs/h.

In spite of the implementation of many new solutions in the machine its results are much worse than it was assumed as far as accessibility, waste and efficiency are analyzed. It was the effect of high expectations to the supplier who introduced untested solutions in the production environment. The lack of engagement of capable people while designing the concept of the machine and its purchasing caused the failing of the project. It should be underlined that the process of machine installation was done unprofessionally as workers were not planned to participate in the training. Summing up, the company bought the expensive machine which was supposed to be much more efficient than the old ones but it appeared that the production costs are much higher at this machine in the analyzed company.

## 5 Conclusions

Automation technology, which is driven by market demands, technical and theoretical developments, has developed significantly in the recent decades. However, there are unforeseen situations, where it is not able to cope with, even regardless of its advancement and extension. On the basis of the analyzed example it can be noticed that implementing automation does not always influence productivity and efficiency. Changeovers can take more time than it was assumed and the prototype solutions can lead to problems. The efficiency of the machine is lower, more waste products are delivered and down time is often present than in the case of older machinery. Some products cannot be delivered due to technical problems while machine adjustments. Thus, the appropriate recognition of the role of human factor in such systems is required. Such systems cannot be designed and operated without the engagement of the experienced and qualified employees. The company has to be prepared to the installation of modern machines and aware of the need of training courses.

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# Burnout Syndrome and Musculoskeletal Complaints in Mexican Middle School Teachers in Ciudad Juarez

**Aidé-Aracely Maldonado-Macías, Jorge García-Alcaraz, Carolina Corchado-Nevarez, Juan Luis Hernández-Arellano and Yolanda Baez-Lopez**

**Abstract** Teachers face highly demanding situations every day. Their jobs are physically and cognitive challenging diminishing their health. The objective of this paper is to determine the level of burnout syndrome (BS) in Mexican middle school teachers and find the association of BS dimensions with musculoskeletal complaints. As methods, the Maslach Burnout Inventory (MBI) and the Bodymap were administered to 168 middle school teachers. Spearman correlation index was applied. Results show that educators suffer from a medium level of BS on the three dimensions. Emotional exhaustion is correlated with pain in the eyes, neck, wrists, shoulders, ankles, the whole arm, the lower leg, and the back. Depersonalization is correlated with complaints in the left shoulder, the left hand, and the knees. Finally, lack of professional efficacy is associated with pain in both arms, hands, wrists, ankles, and the lower back. It is concluded that preventive actions must be taken to avoid serious burnout consequences in vulnerable professions.

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**Keywords** Burnout syndrome · Musculoskeletal complaints · Teachers · Ciudad Juarez · Preventive actions

## 1 Introduction

For more than three decades, research has focused on one syndrome that affects professionals whose work requires intense involvement and interaction with other people. Such a condition is known as burnout syndrome (BS), and it is a psychological disorder that reflects on the workers' responses to constant hostile situations in the workplace [1], such as monotony or excessive exigencies. However, BS can worsen when employees experience their own personal emotional conflicts or work problems, such as a low income. All these situations logically lead to notorious physical and emotional exhaustion that in the end affect work performance if adverse conditions persist [2].

Due to its diverse effects, BS is not a single construct [3]. Instead, it can be perceived in three principal dimensions: emotional exhaustion, depersonalization, and professional efficacy [1]. First, emotional exhaustion derives from work overloads and conflicts, which consume high emotional and physical resources to be able to cope with them. Second, depersonalization is characterized by a distant attitude towards people [4], that is, sufferers tend to act with cynicism as a defense mechanism to cope with exhaustion. Finally, low professional efficacy involves feelings of professional incompetence, little social support, and a lack of efficiency at work [3].

Research on BS has addressed a wide range of professions and areas, especially education, hospitality, and social services, among others [5]. In the educational context, it is long-known that teachers are daily exposed to highly demanding situations [6]. Their jobs can be physically and mentally exhausting and may cause psychological disorders, such as BS, or physical pain, such as musculoskeletal complaints (MC). Unfortunately, such conditions are not only detrimental to the health and performance of educators but also have a negative effect on schools. For instance, academic institutions might have to deal with constant absenteeism and turnover as well as with low productivity rates, since when teachers are exhausted full attention to students may not be offered. In addition, professors with BS are 50 % more likely to quit their jobs within the first five years of their careers [7].

In the case of middle school professors, BS is usually influenced by the working conditions, which sometimes are not completely appropriate if they are compared with facilities offered by college institutions. Similarly, these teachers may experience social isolation due to long working hours; and there is also the issue with low incomes, the excessive number of students within one class, and the particular characteristics of every school, not to mention that stress becomes a constant when educators lack of pedagogical training [8].

Moreover, middle school can be challenging [8] because students at this level must be provided with the essential knowledge and preparation that will allow them to succeed in higher levels and their professional future. Therefore, since the impact of their instruction on students' development is determinant, educators may constantly feel under pressure, and this can increase the risk of suffering from certain diseases or disorders whose effects will reflect on the quality of classes [9].

Finally, as far as musculoskeletal complaints are concerned, even though teaching does not require excessive physical effort, the activities performed on a daily basis for the class can cause physical disorders. In fact, educators often experience pain in the back, the neck, the shoulders, and the hands.

Therefore, it is important to determine the specific causes of both BS and musculoskeletal complaints among middle school teachers as a means to suggest forms of preventing and diminishing them. This would enhance the quality of academic instruction, but, mainly, it will ease teaching for educators. Hence, to determine such information, this research first describes the sample involved in the study. Then, the questionnaire administered to such a sample is validated. Afterwards, the study determines the level of BS suffered by teachers and identifies which burnout dimensions are related to the musculoskeletal complaints that they experience.

Similarly, the main contribution of this paper is the introduction of novel research about the performance and health of middle school educators, since, in the particular case of Mexico, BS and musculoskeletal complaints have not been associated when studying such a population. Also, a second contribution is the provision of quantifiable information on musculoskeletal complaints suffered by teachers in secondary education. Currently, the Institute for Social Security and Services for State Workers (ISSSTE) does not rely on such data. However, they can be useful to address and prevent the syndrome.

## 2 Literature Review

### *2.1 Burnout Syndrome in Teachers*

Burnout syndrome has been the focus of study in many professions. As far as education is concerned, even though some research has demonstrated low incidence of BS in teachers, this does not mean that the problem is inexistent, or that poor work performance, work dissatisfaction, and low motivation, among others, are alien to the teaching community. In fact, such obstacles at work are regular topics in casual conversations [10].

According to a study carried out in Spain, middle school teachers that have more students experience the highest levels of BS in comparison with those who have fewer students [10]. Authors associated these results to the difficult work environment caused by large classes, which does not allow for the implementation of innovative teaching techniques [11]. However, the study did not present statistical evidence to demonstrate that the educational level was actually relevant to results [12].

From a similar perspective, research on teachers' efficacy has shown that several external aspects affect their performance, and organizational factors are often the most common issues. For instance, it was demonstrated that groups with a rational culture were more likely to suffer from BS than groups having a more consensual philosophy. This means that participative cultures are actually less affected by the condition [13].

Other organizational elements having negative effects on the professional performance of teachers are workloads derived from class activities and both the attitude and quality of leadership from superiors [14]. However, it was also found that poor commitment from students to the class and their behavior—which may be stressful, as well as emotional exhaustion, depersonalization, feelings of professional ineffectiveness (BS dimensions), and constant work dissatisfaction were negative variables [15]. Furthermore, as regards the physical work environment, most teachers have highlighted noise, inappropriate classroom illumination and temperatures, and musculoskeletal complaints [16].

A study aimed to define the epidemiological profile of BS in middle school educators also obtained relevant results. First, it found that BS was strongly related to age and seniority, although there was no apparent direct relationship between BS and the gender of teachers [17]. Likewise, it determined that BS reflected more on emotional exhaustion [9], and participants were then affected in terms of the lack of professional effectiveness and depersonalization. Finally, the epidemiological risk profile obtained was a 43-year-old female, with no stable partner and no children, and with less than 19 years of service in her profession [17].

As regards the physical consequences of BS, research simultaneously carried out in six Latin American countries sought to explore the work and health conditions experienced by teachers of elementary school. The study was developed by the United Nations Educational, Scientific and Cultural Organization (UNESCO), and it found that an elevated percentage of the evaluated teachers suffered from insomnia, anxiety, and lack of concentration [18]. As for the three dimensions of burnout, on the one hand, UNESCO determined that the low professional efficacy was the most related to some variables involved in the development of mental illnesses. On the other hand, depersonalization showed little presence in the sample surveyed, which was a positive aspect. Similarly, the research determined that the most experienced physical and physiological complications included pain in the back and the neck, headaches, cold and flu, voice disorders, loss of appetite, and insomnia. However, from a different perspective, the psychological complications of teachers involved feelings of having little personal time, mental exhaustion, a hectic state, forgetfulness, lack of concentration, and easy irritability. Finally, the study concluded that while elementary teachers suffered more from physical pain, middle school educators showed a higher prevalence of psychological disorders [12].

Burnout syndrome, however, can be also associated with the way in which teachers perceive their work [19]. Those who see teaching as their vocation are less likely to suffer from such a condition, while teachers who view it as a simple job are more prone to certain physical and psychological problems. Finally, age must not be forgotten as an important factor. As individuals become older, and unhealthy habits are preserved, the risk of suffering from burnout syndrome increases.

### *2.2 Musculoskeletal Complaints in Teachers*

Epidemiologic research has categorized musculoskeletal complaints as some of the most common and expensive health conditions for both developed and developing countries [19]. Likewise, it was determined that BS could predict these complaints [20], which usually affect tendons, nerves, and blood vessels [21], and compromise tissue integrity and the movement of the limbs [22]. However, other negative effects of musculoskeletal complaints include a limited ability to perform certain tasks, work absenteeism, incapacities, early retirement, and a low quality of life [23]. From this perspective, the costs derived from treating musculoskeletal complaints has risen up to 50 billion dollars in the United States, including compensation expenses, lost shifts, and the impact on loss of productivity.

In the particular case of teachers, musculoskeletal disorders are experienced in numerous parts of the body, such as the hands and the wrists [24], or the trapezius and deltoid muscles, as a result of constant movements of the arms. Similarly, joint disorders are present as a consequence of continuous hand and wrists movements (to grade assignments or call the roll, for example). In addition, other activities can have a negative impact on the health of middle school teachers. These include speaking and standing up for long moments (to explain a topic, get the attention of students, or monitor the class) and the lack of physical spaces to rest during the breaks [25]. Moreover, it was found that constant exposure to the computer caused pain in the neck [26], while back pain and injuries due to repetitive movements were the major cause of incapacities among Spanish teachers [27]. Finally, a study carried out among teachers in Brazil associated long working days with the prevalence of headaches, back pain, limb pain, and cramps [28], whilst other studies determined that musculoskeletal complaints were more present in women [29] and teachers [30].

## 3 Methodology

The methodology of this research follows a descriptive and transversal approach, and it is also causal and correlational. Instruments and methods are described in the following sections.

### *3.1 Instruments*

This study relied on three measuring instruments and combined them in a single final instrument. Section 1 of the survey was thus composed of a structured interview to obtain sociodemographic data from the sample. Information requested in this section included personal, academic, and work information (age, marital status, number of children, type of contract, as well as time spent on lesson planning and teaching hours, and whether participants suffered from any chronic disease and had a second job).

The second section of the survey involved the Maslach Burnout Inventory for educators (MBI-Educators Survey, MBI-ES). The purpose of this section was to determine the level of BS suffered by participants, and this was achieved through 22 items measuring the three dimensions of BS: emotional exhaustion (9 items), depersonalization (5 items), and professional efficacy (8 items). The MBI-ES includes a seven-point Likert scale ranging from “never” (0) to “always” (6).

The third and final section of the composed instrument included the Bodymap assessment [31]. Such an evaluation addresses the body in sections, and respondents must report if they suffer from any pain or disorder in the parts of the body listed. Similarly, participants must specify both the frequency and intensity of such pain. On the one hand, the frequency was measured with a scale ranging from “never” (0) to “almost every day” (3). On the other hand, pain intensity was determined with an eleven-point scale, ranging from “no pain” (0) to “extremely uncomfortable (10).” The product of intensity and frequency results in a third variable known as severity.

Data obtained from the composed instrument were captured in an Excel® database, and they were later analyzed by statistical software SPSS®. This program was used to both validate the composed instrument, by using the Cronbach’s alpha coefficient, and analyze data from the total sample. Materials employed at this stage included black and blue pens, a personal computer, a printer, and programs Microsoft Word®, Microsoft Excel®, and IBM SPSS®.

## *3.2 Methods*

The research was carried out in the Mexican City of Juarez middle schools. The sample comprised teachers that worked in mixed shifts under full-time positions or indeterminate internships. According to the Secretariat of Public Education (SEP) of Mexico, the city of Juarez, Chihuahua, caters for 49 technical middle schools and 51 general middle schools. Hence, data were collected using the cluster sampling technique. That said, the city was divided into sectors to identify the technical and general middle schools comprised in each zone. Also, to determine the number of participants, statistics from the Educational Services of the State of Chihuahua (SEECH) were considered. This institution determined that in Ciudad Juarez 3734 teachers had enrolled in the 2013–2014 school year. Such information was introduced in the sample calculator on the website www.netquest.com. Results were obtained with 95 % of confidence, and the size of the sample was 349 teachers.

After this procedure, undergraduate students were trained in the correct administration of the questionnaire. Particular emphasis was made on how to address items from the last two sections of the instrument, as well as on how to assist respondents. Finally, the survey was randomly administered during two periods, from May to June 2014, and from August to September 2014. To achieve this, appointments were scheduled based on the general school calendar for secondary education. The purpose of this was to gather all participants from a same institution in a single session. In these sessions, administrators first explained the objective of the research and provided the necessary instructions to successfully respond the survey. Then, respondents signed a consent letter that allowed authors of this study to use information provided. Finally, administrators verified the successful completion of the surveys and a number was assigned to each one of them.

Information gathered was first captured in a database. Then, such data were debugged by substituting missing values with the median. Next, the Cronbach's alpha index was used to verify internal consistency of the survey and determine the presence of BS in the sample based on three levels: low, medium, and high. To achieve this, percentiles 33.3 and 66.6 were used as cutoff values. Results obtained for every dimension are introduced in Table 1 and matched those from previous studies [20]. Finally, the Spearman correlation index was calculated with 95 % of confidence level to determine the relationships between BS dimension and musculoskeletal complaints.

As final observation, it is worth mentioning that special consideration and a different interpretation was given to data obtained from pregnant women. Since they are more prone to changing sleep patterns [32], they can feel more tired than usual. Such a physical exhaustion affects their quality of life and influences the incidence of depression and anxiety.

**Working hypotheses**: Table 2 lists the hypotheses proposed for this study as well as their statistical representations. All of them were constructed based on the literature review. In addition, they were formulated as sentences describing the relationships between variables (dimensions of BS and musculoskeletal

**Table 1** Levels of BS for every dimension

| BS level | Emotional exhaustion | Depersonalization | Professional efficacy |
|---|---|---|---|
| High | 27> | 10> | 40> |
| Medium | 19–26 | 6–9 | 34–39 |
| Low/very low | <19 | <6 | 0–30 |

**Table 2** Alternative and null hypotheses

| Research hypothesis | Statistical rep. |
|---|---|
| $H_0$: There is a direct and negative relationship between emotional exhaustion and the severity of musculoskeletal complaints | $H_0 : \rho_{X_1 Y} \leq 0$ |
| $H_1$: There is a direct and positive relationship between emotional exhaustion and the severity of musculoskeletal complaints | $H_1 : \rho_{X_1 Y} > 0$ |
| $H_0$: There is a direct and negative relationship between depersonalization and the severity of musculoskeletal complaints | $H_0 : \rho_{X_2 Y} \leq 0$ |
| $H_1$: There is a direct and positive relationship between depersonalization and the severity of musculoskeletal complaints | $H_1 : \rho_{X_2 Y} > 0$ |
| $H_0$: There is a direct and positive relationship between low professional efficacy and the severity of musculoskeletal complaints | $H_0 : \rho_{X_3 Y} \geq 0$ |
| $H_1$: There is a direct and negative relationship between low professional efficacy and the severity of musculoskeletal complaints | $H_1 : \rho_{X_3 Y} < 0$ |

**Table 3** Sociodemographic data of the sample

| Options | | Frequency | Percentage (%) |
|---|---|---|---|
| Age | 60 years old or more | 3 | 1.8 |
| | 50–59 years old | 34 | 20.2 |
| | 40–49 years old | 69 | 41.1 |
| | 30–39 years old | 43 | 25.6 |
| | 20–29 years old | 17 | 10.1 |
| | Not provided | 2 | 1.2 |
| Marital status | Single | 30 | 17.9 |
| | Married | 108 | 64.3 |
| | Free union | 12 | 7.1 |
| | Divorced | 13 | 7.7 |
| | Other | 2 | 1.2 |
| | Not provided | 3 | 1.8 |
| Children | From 0 to 2 | 113 | 67.3 |
| | From 3 to 5 | 48 | 28.6 |
| | From 6 to 8 | 1 | 0.6 |
| | Not provided | 6 | 3.6 |
| Chronic diseases | Yes | 34 | 20.2 |
| | No | 133 | 79.2 |
| | Not provided | 1 | 0.6 |
| Type of contract | Permanent | 118 | 70.2 |
| | Indefinite internship | 33 | 19.1 |
| | Definite internship | 12 | 7.1 |
| | Other | 1 | 0.6 |
| | Not provided | 5 | 3.0 |
| Second job | Yes | 23 | 13.7 |
| | No | 135 | 80.4 |
| | Not provided | 10 | 6.0 |
| Hours of lesson planning per week | 9 h or more | 26 | 15.5 |
| | From 6 to 8 h | 48 | 28.6 |
| | From 3 to 5 h | 60 | 35.7 |
| | From 0 to 2 h | 22 | 13.1 |
| | Not provided | 12 | 7.1 |
| Teaching hours per week | 40 h. or more | 21 | 12.5 |
| | From 31 to 40 h | 68 | 40.5 |
| | From 21 to 30 h | 20 | 11.9 |
| | From 11 to 20 h | 29 | 17.3 |
| | From 0 to 10 h | 19 | 11.3 |
| | Not provided | 11 | 6.5 |

complaints). For the null hypotheses, three types of relationships were considered: direct and positive, direct and negative, or inexistent. Alternative hypotheses are opposite to null hypotheses.

# 4 Results

## 4.1 Description of the Sample

The final sample included 168 middle school teachers from different middle schools in Ciudad Juarez. From this total, 72 were male respondents, 95 were females, and one respondent did not specify his/her gender. Table 3 shows the sociodemographic information of the sample. Thus, most participants are 40–49 years old (41.1 %), married (64.3 %), and with no children, or no more than two (67.3 %). Likewise, the majority does not suffer from any chronic disease (79.2 %) and holds a permanent contract (70.2 %), which suggests that most teachers interviewed feel secure at work. From a similar perspective, 80.4 % of participants mainly work as teachers, whilst most of them do not have another job. Finally, the majority of the sample weekly spends from three to five hours planning (35.7 %), and 40.5 % teaches from 31 to 40 h per week.

## 4.2 Instrument Validation

The survey was validated with the Cronbach's alpha index. Values obtained in the MBI-ES section were 0.831 for emotional exhaustion, 0.591 for depersonalization, and 0.738 for professional efficacy. Similarly, the coefficient of the Bodymap assessment was 0.950. Based on these four results, it was concluded that the survey had enough reliability for the purpose of this research.

## 4.3 Results Obtained in BS and Musculoskeletal Complaints

Partial results were obtained from the survey administration, which were needed for the analysis of data. Therefore, the mean was obtained for every dimension as Table 3 shows. The arithmetic mean for emotional exhaustion was 22.256, while 5.3988 and

**Table 4** Levels of burnout syndrome for the sample

| BS level | Emotional exhaustion | Depersonalization | Professional efficacy |
|---|---|---|---|
| Low | <18 | <2 | >42 |
| Medium | 19–29 (*24.2560*) | 3–6 (*5.3988*) | 36–41 (*37.6480*) |
| High | >30 | >7 | <35 |

**Table 5** Correlation matrix

| | Emotional exhaustion | Depersonalization | Professional efficacy |
|---|---|---|---|
| Eyes | $P = 0.004$; CC = 0.204 | | |
| Neck | $P = 0.000$; CC = 0.261 | | |
| Left shoulder | $P = 0.000$; CC = 0.281 | $P = 0.035$; CC = 0.141 | $P = 0.045$; CC = −0.131 |
| Left elbow | | | $P = 0.004$; CC = −0.202 |
| Left forearm | | | $P = 0.049$; CC = −0.128 |
| Left hand | $P = 0.004$; CC = 0.203 | $P = 0.022$; CC = 0.155 | $P = 0.01$; CC = −0.179 |
| Buttocks | $P = 0.005$; CC = 0.201 | $P = 0.034$; CC = 0.141 | $P = 0.015$; CC = −0.167 |
| Left leg | $P = 0.011$; CC = 0.176 | | $P = 0.006$; CC = −0.194 |
| Left knee | $P = 0.003$; CC = 0.216 | $P = 0.043$; CC = 0.133 | |
| Left calf | $P = 0.003$; CC = 0.214 | | $P = 0.005$; CC = −0.197 |
| Left ankle | $P = 0.009$; CC = 0.183 | | $P = 0.006$; CC = −0.196 |
| Upper back | $P = 0.002$; CC = 0.219 | | |
| Right shoulder | $P = 0.02$; CC = 0.159 | | |
| Right elbow | $P = 0.014$; CC = 0.17 | | $P = 0.002$; CC = −0.217 |
| Right forearm | $P = 0.045$; CC = 0.131 | | $P = 0.014$; CC = −0.169 |
| Right wrist | $P = 0.006$; CC = 0.192 | | |
| Right hand | $P = 0.004$; CC = 0.206 | | $P = 0.031$; CC = −0.145 |
| Lower back | $P = 0.001$; CC = 0.241 | | $P = 0.005$; CC = −0.197 |
| Right leg | $P = 0.001$; CC = 0.228 | | $P = 0.01$; CC = −0.18 |
| Right knee | $P = 0.001$; CC = 0.235 | $P = 0.017$; CC = 0.163 | |
| Right calf | $P = 0.000$; CC = 0.252 | | $P = 0.003$; CC = −0.214 |
| Right ankle | $P = 0.001$; CC = 0.241 | | $P = 0.026$; CC = −0.15 |

37.648 were obtained for depersonalization and professional efficacy, respectively (Table 4). All results corresponded to a medium level of BS. Table 5 summarizes the musculoskeletal complaints reported by teachers as well as their relationships with the three dimension of BS. CC means to correlational coefficient and P value indicates the significate relationship considering at a 95 % confidence interval.

## 5 Conclusions and Recommendations

The majority of the sample were teachers from 40 to 59 years old, who are mostly married and do not have children, or have maximum two. Also, it was concluded that the sample in general is healthy, since chronic diseases were little reported. Furthermore, as regards work information, permanent contract prevailed, and the majority of the teachers usually spend from three to five hours planning, while they teach from 31 to 40 h per week. Finally, the validity and reliability of the survey employed to gather such data were demonstrated by the Cronbach's alpha index.

As for the prevalence of BS, it was found that middle school teachers suffered from a medium level of burnout in its three dimensions. Therefore, several strategies should be considered by schools in their work environments in order to help professors reduce stress. Some of these strategies include encouraging relaxation techniques, exercise routines, and consultations with health care professionals.

This research also detected significant relationships between dependent and independent variables (BS dimensions and musculoskeletal complaints). Such relationships were described by the alternative hypotheses. Therefore, all null hypotheses were discarded based on results from the correlation matrix. For the first hypothesis (H1), the analysis of data showed that 84 % of the body parts involved in musculoskeletal complaints were directly and positively related to emotional exhaustion. For the remaining 16 %, no evidence was obtained to state such a relationship.

Similarly, the second hypothesis determined that depersonalization had a direct and positive impact on the severity of musculoskeletal complaints, even though this last variable was merely significant at 4 %. For the remaining 96 %, no evidence was obtained to infer such a relationship.

Finally, as regards hypothesis 3, a direct and negative relationship was stated between professional efficacy and the severity of musculoskeletal complaints. In fact, 60 % of the body parts were significant related to such complaints. For the remaining 40 %, no statistical evidence was obtained to infer such a correlation.

In conclusion, results obtained match the literature review by showing that middle school teachers often experience pain in the back and the neck [12], and that dimensions of BS are associated with musculoskeletal complaints [24, 29, 30, 33, 34]. Moreover, although relationships found between variables are weak, they are significant and must be seriously considered.

Finally as proposals, this research first suggests the legislative support from the Education Law of the State of Chihuahua to protect the integral health of teachers.

An additional article in this law could address the emotional health of educators, which is as important as their physical health. Similarly, additional statistical evidence to describe the incidence of BS among teachers in Ciudad Juarez will help ISSSTE, school boards, and headmasters support the medical assessment and monitoring of educators.

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# The OHS Management in a Development of Small Enterprises (For Example of Welding Factory)

**Adam Górny**

**Abstract** In order to grow efficiently and sustainably, an enterprise needs to apply solutions which will allow it to improve all areas critical for its overall performance. One such growth-critical area is safety management which, if pursued appropriately, will help a business create a proper working environment based on innovative solutions and ultimately achieve an active market presence. No organization will survive on the market without realizing the need to embrace changes which will boost its ability to act. The change needs to be adopted systemically by relying on enhanced capabilities to satisfy customers and by perceiving workers as internal clients. This is particularly crucial for small enterprises, which tend to consider skilled employees as their sole resource. This article discusses risk assessment as a way to boost an organization's performance. Such assessment is viewed as part of systemic management. The necessity of risks assessment to both arises from the provisions system and is indicated on basis of a tiered way to improve of organizations functioning (Górny in Proceedings of Occupational Safety and Hygiene (SHO 2015). Portuguese Society of Occupational Safety and Hygiene (SPOSHO), Guimarães, [1]; Vlek and Stallen in Acta Psychol 45:273–300, [2]). A case of a welding factory has been selected to demonstrate how an organization's performance can be improved by employing solutions suited for a small business and by relying on risk assessment.

**Keywords** Safety and ergonomics · Development · Improvement · Systemic approach · Welding factory

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## 1 Introduction

To achieve its desired improvements, an enterprise needs to apply solutions which will allow it to accomplish the desired growth objectives and meet stakeholder expectations. A major role in such solutions is played by customers who are vital for an enterprise's market success.

A systemic analysis of the issue shows that customers are equally significant for ensuring that an enterprise's processes run efficiently and effectively. Some of the customers of such processes may be internal users of task outcomes. Such users additionally influence the way in which tasks are performed. When examining the specific nature of occupational health and safety management, internal customers should be seen as beneficiaries of efforts aimed at ensuring safe working conditions with a view to making a given business organization grow more robustly. Lack of safety can be regarded as an important factor, negatively affecting in the possibility of its effective functioning on the market.

Such efforts are particularly important for small businesses whose employees are fundamental for their competitiveness. It is therefore essential to equip them with a working environment which will contribute to boosting their performance. A systemic analysis of the issue demonstrates that such an environment will drive an enterprise's growth as long as it makes improvements and incorporates them into its day-to-day work routines. In these conditions improvement becomes an integral part of the organization operation [3–5]. Must be assumed, that the organization which does not take improvement action will have difficulties in meeting changing requirements and expectations of external customers.

By analyzing the problem in relation to the issues in the area of health and safety, first of all, should be noted, the related the possibility of safely perform professional tasks by the employees and the company's market position [6, 7].

## 2 Improvements in Occupational Health and Safety Management System as Driver for Corporate Growth

In the systemic approach, an organization is a system dependent on its environment and affected by internal as well as external factors. In order to ensure the effectiveness of the shaping of safety as particularly important should be treated internal factors, determining implementation processes for which the customer is employee of a company [8, 9].

By and large, enterprises operate to achieve their objectives while ensuring a proper cost-benefit ratio. In the context of the central focus of this paper, it is worth noting the significance of non-financial and hybrid effectiveness assessment methods [10, 11]. Such methods are particularly crucial for a company's sustainability as they require that the traditional view of effectiveness be extended to include non-economic and, in particular, technical considerations. The extended approach to effectiveness also encompasses an enterprise's impact on its immediate and more remote environment. An assessment of a business organization's management efficiency should include evaluations of process effectiveness (i.e. the degree to which an organization manages to meet its targets) as well as assessments of success in adhering to the aforementioned principle of rational resource management (i.e. the cost-benefit ratio). Therefore, evaluation of the effectiveness of the company's activities is related to finding the factors determining its development, which allow to maximize the effects of actions taken. The search includes all areas of activity, both organizational and technical help, enhance the company's position [7, 12] and obtaining satisfaction of employees [3, 5, 8, 13, 14].

To improve a system's effectiveness, one needs to identify the desired assessment outcomes, define a frame of reference and perform the actual assessment. In economic terms, such effectiveness may be seen as striking a balance or an equilibrium between costs and benefits [9].

An organization's improvement effort should extend to its entire environment and all of its stakeholders. By bringing together all components which allow the overall system to operate, an organization achieves a new improved quality of life [11, 15, 16]. To accomplish the desired outcomes, an enterprise needs to:

– identify areas for improvement,
– define the actions to be taken,
– devise an action plan (strategy),
– deploy the adopted strategy.

The benefits of achieving economic, social and environmental equilibria and the ways to use them to support the systemic effort to improve occupational safety are shown in Table 1.

**Table 1** Description of benefits resulting from well-balanced activities

| Area of equilibrium | Prospective benefits |
|---|---|
| The business equilibrium | – customer satisfaction,<br>– new business,<br>– improving the quality and productivity at work,<br>– innovation capabilities,<br>– employee satisfaction,<br>– employee loyalty |
| The social equilibrium | – occupational safety,<br>– reduced accident and disease rates,<br>– social benefits of improved working conditions,<br>– improving well-being at work (ensuring the welfare at work),<br>– more flexible work,<br>– information policies |
| The environmental equilibrium | – responsibility for work performance,<br>– ability to reduce environmental costs,<br>– reduced environmental impact |

*Source* Author's work on basis [17–19]

They can be construed as benefits of implemented measures, consistent with the principles of corporate social responsibility [19]. The actions undertaken allow to [17, 19]:

- engage the leadership in taking action to improve safety, and of showing interest and concern for safety of employees,
- improve communication related to informing employees about any hazards,
- realize education on health and safety, adapted to the job specific and the needs of employees,
- motivate employees for safe behavior and show appreciation to employees working safely,
- ensure cooperation between employees and ensure an atmosphere of trust between management and employees, and between employees.

In a natural way, these rules can be associated with shaping of work safety system, connecting all areas of the enterprise in order to improve safety. Secondary, but also a very important effect of improvement is the result of increase in the company's ability to realize production and services for customer satisfaction on the satisfactory level. This is a result of implementation of the process approach, which allowing mutual adjust yourself to the needs of all executors of processes [14].

However, to maintain required level of management requires improvement of management system. This improvement to be understood as a consistent act of pursuing goals, that change with development of the market, technology, customer awareness, legislation, etc. In effect, to yield the possibility of providing customer satisfaction [5, 8, 20].

To improve their occupational health and safety management system, organizations must undertake the usual system improvement measures (such as audits, reviews, corrective and preventive measures). A special approach is required to account for the nature of small enterprises. In such organizations, the systemic approach should be guided by the principles whereby [14]:

- the owner is responsible for the state of occupational safety,
- every accident is preventable,
- all employees are required to adhere to safety rules,
- the owner is responsible for assessing safety,
- all causes of accidents and injuries are examined on an ongoing basis,
- the safety level achieved by an organization determines its success,
- a high safety level is achieved only where all workers act appropriately.

In real life, achieving desired outcomes depends increasingly on direct horizontal communication among workers.

Lack a complex organizational structure, characteristic for small businesses greatly simplifies the task. As a result, allowing to simplify the process undertaken improvement activities.

# 3 Application of System Approach for Improve Occupational Safety

## *3.1 Conditions for Improvement*

The primary purpose of improving the working environment is to ensure that workers feel well in their organizations and are inspired to work more productively and creatively. Working environment improvements rely on solutions whose effects are sustained. To secure opportunities for changing and effectively improving the working environment, it is critical to strengthen factors which affect working conditions [21]. In Poland, the role of the management is commonly seen as that of leaders who define objectives and pursue them with the use of resources, processes and information. Such a pursuit takes place in an organization's existing external (legal, social, economic, etc.) environment. This role should be performed efficiently and effectively in keeping with the social principles which define socially responsible ways of doing business.

Occupational health and safety management covers all general aspects of business management to the extent to which they relate to growth and to pursuing occupational health and safety policies. A key factor for securing occupational health and safety within organizations and, as is often the case, using improved safety as leverage for growth, is management efficiency. Such efficiency can be defined as proficient control over re-sources, processes and information to achieve desired results [13]. Simultaneously management efficiency determines the possibility of company development.

Growth in all areas that are of importance for an enterprise's market position greatly improves an organization's ability to survive [8, 22]. This makes innovation policies particularly critical. Innovation in the area of safety at work should be treated as an opportunity to use solutions which contribute to increased work opportunities, whilst also increasing the importance of the humanities aspects, related with ergonomic factors influencing the growth of comfort in work. Innovation tends to be vital for an increasingly broader scope of business operations. These include occupational safety, the protection of employee health and general management aimed at eliminating hazards and strenuousness. More and more often these actions are taken based on the normative guidelines as a basis for the development of standards for the management of occupational health and safety and the principles of excellence taking into account the possibility of human functioning [3, 23, 24].

The major prerequisites for ensuring improvements in an organization's occupational health and safety management system are to [8, 18]:

- inspire and satisfy employee expectations and aspirations,
- establish an atmosphere of mutual trust and respect,
- support any employee ideas which produce benefits,

- encourage employees to raise and discuss issues and contribute to their resolution,
- have the management promote reliable safety assessments and the use of their out-comes to formulate and take corrective measures,
- have workers help develop and implement occupational health and safety improvement plans,
- have workers remain in contact with occupational health and safety officers at all times and approach them to consult any risks and hazards,
- examine hazards and formulate safe working procedures,
- formulate occupational safety principles and ensure they are duly followed.

Occupational health and safety management must become an integral part of a company's management system and, as such, help modify working conditions, improve the bottom line and boost the organization's market standing. Is a necessary condition to ensure the effectiveness of organization for changing market conditions.

### 3.2 Influence an Applied Approach on Choice of Improvement Actions

The tool to be used to assess safety and identify a proper course of action is occupational risk assessment. Hazards arise as a result of inconsistencies between specific solutions which result in the deterioration of worker health. Human health and life are at risk wherever workers are exposed to solutions which are inconsistent with health requirements. The risk assessment should be treated as an integral part of the safety management system in the enterprise. The scope of its implementation is not directly related to system of applied approach. However, the way conduct it should be included in the records of system. In particular this concerns identification of hazards and resulting of them improvement actions (preventive and corrective) [2, 5, 8].

Risk assessment findings may serve as indicators for assessing systems of occupational health and safety management. Measures taken to reduce risk levels additionally help improve the effectiveness and efficiency of occupational health and safety management [13, 24].

The author has made sure it would be possible to improve the safety of the plant's production processes (welding) by assessing a workstation used by five welders performing similar tasks. The workers perform common welding tasks (gas and electrical welding, electric arc or oxygen cutting) during an 8-hour work day [25–27]. Such tasks include:

- preparing the workstation for electrical or gas welding,
- performing the welding tasks specified in relevant job descriptions,

– performing any extra bench work associated with welding (such as cutting, filing, bending, cleaning, polishing),
– performing checks of work outcome quality and removing defects on an ongoing basis.

Additionally, the workstation clean-up carried out upon the completion of welding proper involves moving such various items as gas cylinders, welding equipment and welded items [26, 28]. The hazards involved in such work are summarized in Table 2.

A study of irregularities has helped us identify corrective measures associated with the systemic approach and designed to improve working conditions.

**Table 2** Hazards reflecting the safety status and suggested improvements

| Status assessment | | Improvements made (corrective measures appropriate for discovered hazards) |
|---|---|---|
| Underlying causes of hazards | Description of hazards | |
| Improper clamping of cut and welded items | Shifting items hit worker and inflict minor cuts and abrasions | – use gloves as protection against sharp edges and abrasive surfaces,<br>– use proper footwear,<br>– remain on high alert,<br>– follow detailed work instructions which set out ways to clamp cut and welded items |
| Drops of melted metal produced during welding and hot welded items | High temperature of worked items causes burn wounds | – use personal protection including proper protective clothing, face shields, gloves and footwear,<br>– discuss hazards during daily worker meetings |
| Radiation from electrical arc during welding | Ultraviolet and infrared radiation cause damage to exposed body parts, conjunctivitis and retinal lesions | – use helmet shields, hoods, button up working clothes,<br>– use proper welding gloves,<br>– use proper screen partitions,<br>– discuss hazards during daily worker meetings |
| Prolonged work in forced postures (with inadequate protection) | Static physical loads strain muskoskeletal system and cause osseous and arthral degeneration | – issue knee pads to workers and ensure they wear them,<br>– rotate workers between strenuous assignments,<br>– observe applicable work standards |

*Source* Author's work

### 3.3 The Benefits of Using System Approach (for Safety and Development of Company)

Occurrence of irregularities in the work environment, giving rise to the burden for employees and the risks to safety requires application adequate improvement activities. These measures should include all identified irregularities, contributing to increase work opportunities and the efficient functioning of company [12, 29].

Applied activities allows obtain a number of advantages, which can be identified with aspects of safety, and to influence on development of the company. By the use of systemic policies can identify a common direction actions. This is consistent with the principles of hazards minimizing, according to which actions must be coherent with the general principles of the organization functioning.

The primary achieved benefits include [5, 8, 13, 18]:

- taking care of work conditions (including work safety),
- the widely understood, going beyond legal requirements care about environment,
- care about employees, including care determined by the size of cost for prevention safety,
- maintaining good relationships between employees and management,
- taking care of good relations in the place of work,
- adherence to rules and professional regulations,
- trainings, the scope of which is related to the nature of the job,
- the development of professional competence, particularly with regard to the ability to assurance of safety work,
- medical protection of workers (including additional medical checks and vaccinations),
- the efficiency of the exchange of information (including hazard information and occupational risk),
- used technical and organizational measures to protect against hazards,
- shaping the culture of conduct in the case occurrence of hazards and nuisances.
- maintaining proper relations with local communities,
- environmental care, taking into account its impact on the conditions of work.

To ensure effective growth, an organization should see improvements in all of the above-mentioned fields (areas of equilibrium) as essential. Efforts need to be properly coordinated. The key to the new approach is to adopt an improvement methodology which seeks to involve the largest possible number of organization members and coordinate their efforts closely.

Ideally, every technology and work-flow/production arrangement should be checked for accident hazards. This would help ensure that occupational safety is brought up to the expected standard and made to support enterprise growth.

When assessing hazards and selecting post-evaluation measures, particular attention needs to be paid to the human factor which is crucial for ultimate outcomes [2, 30]. Such measures are of growing concern, especially for organizations seeking to become socially responsible.

## 4 Conclusions

The most effective way to improve occupational safety in a systemic approach is to arrange production processes and work-flows so as to eliminate any possibility of an employee committing errors and endangering human safety. To that end, organizations should search for technologies and organizational arrangements which will force all involved parties to behave safely. Measures for improving occupational safety management are designed to rule out high-risk situations. Production technology and work-flow designers ought to bear in mind that workers can be counted on to “take advantage” of every available opportunity to cause an accident and every circumstance which may potentially lead to one [6, 14].

The systemic approach to occupational health and safety is a tool for making a set of systemically ordered measures influence the culture of safety seen as part of organization culture and, as a consequence, affect an organization’s market position. By adopting an occupational health and safety management system, an employer gains the capability to make best use of its resources to achieve such measurable economic effects as lowering the cost of occupational accidents and diseases. In addition, an employer’s care for the well-being of its employees at the workplace will boost worker morale and dedication consequently increasing worker productivity. This should be seen as an essential factor for the growth of small enterprises no matter what business they are in.

Such an approach will also make the public perceive organizations favorably, value their products and services and generate additional business.

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# Comparative Study on User and Manufacturer Perception of Ergonomics Requirement on Sofa Design in Malaysia

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**Abstract** Development of ergonomic sofa design is a design process includes the basic framework specification, type of material, consideration of sofa features and sofa production methods that is applied on the sofa design. One of the methods that can be used in developing most appropriate design is by applying the process of upgrading existing sofa furniture through structural development that are based on user and manufacturer perception. Therefore, the goal of the paper is to develop a conceptual design for ergonomic sofa based on the user and manufacturer perception. To achieve this goal, a survey involving 30 respondents of sofa makers and sofa consumers was conducted to obtain feedback regarding the conceptual design of ergonomic sofa. The questionnaire survey had emphasize on the concept of sofa, general features of sofa, basic materials of sofa, basic color scheme and price range based on consumer perception and also focused on the basic specifications and material dimensions of sofa materials used. The results of data analysis show that the size of basic dimensions and materials is essential in designing an ergonomic sofa and user preferences have been identified. The survey is very important to find out the basic specifications in the development of ergonomic design through perception of sofa maker and consumers. The future stage of the research will focus on the incorporation of anthropometric data in order to address the innovative criterion of the development.

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**Keywords** Conceptual design · Ergonomic sofa concept · Consumer preferences · Manufacturer perception · Productivity implications

## 1 Introduction

Conceptual design is one of the major determinants of the direction and potential of a furniture product. Concepts and methods adopted in the development process of a furniture product may lead to a great design-to-production process in the effort to meet consumer tastes as well as to provide effective implications of industrial furniture products in Malaysia to the society. Users normally have different tastes and hence, preferences. At the same time, users of manufacturing industry of contemporary furniture also have different needs and requirements [1]. As a results, every individual will try to meet their needs and requirements. However, not all needs and requirements can be met due to limited supply of materials and limited human capacity at any one time. The design concept initially was considered to be the most sensitive design, critical and difficult to create a product [2]. According to Nevins et al. [3] this is especially affecting the cost, robustness, manufacturing methods in the design and development of products. The study indicates that the future of furniture industry depends on the extent to which it is able to respond to the needs of present and future situation whereby government support should be to strengthen the competitiveness of French furniture entrepreneurs [4]. Although the functions, objectives and functions of a design as a whole is not clear, the attention given to the concept of ergonomics in product design and response from consumers will generally provide comfort and suitability to the limits of human physical capabilities and produce a high quality product [5]. A design was created to provide a basis for process design specification in understanding the creation of quality product identity [3].

Although the objectives and functions of a design as a whole is not clear, generally, conceptual design is one of the most important aspects in determining the characteristics of a furniture product. Assessment of functions and technical methods in design concepts need to be upgraded to meet customer needs and satisfaction [6]. For example, Gonzalez et al. [7] created a design that should provide a conceptual framework for mold design process as an assessment and understanding of users in establishing the identity of the product quality.

Regardless of the confrontation that exists between different tastes and preferences of the users against different needs and requirements of the manufacturers the trend today focuses on designing sofa of superficial beauty at an affordable price. Sofa users have mostly focused more on quality and comfort while sitting. History shows that most people do not want to think about the chairs they sit on, yet highly complex tasks are involved in producing the chair that they need to learn to sit down and finish it [8].

However the reality of concepts and methods in industrial design in Malaysia at present is more focused on designing a beautiful, inexpensive and brief sofa [9]. Many studies have focused on risk factors and actions in a design that increases the probability of pain, suffering and injury due to a mistake at the early stage of design process. This risk is reduced when the seat support area and the dynamic nature of the existing movement exist [10]. Although ergonomics is one of the functions that is taken for granted, contributions of past studies have had many impacts on a perfect product [11, 12]. Hence, human consumption factor in determining the function and role of a product should be taken into account in the process of designing a product. Moreover, most entrepreneurs do not pay sufficient attention to Malaysian identity in furniture industry products. Rather, they tend to focus on the needs of users who do not show obvious preference to product with Malaysian identity. Ratnasingam et al. [13] state that Malaysia has many experienced Bumiputera entrepreneurs but they are lacking in the technical and business knowledge.

More than that, Malaysian entrepreneurs are claimed to be not taking advantage of the native talents to develop furniture designs that effectively reflect the identity of Malaysia. Hence, human consumption factor in determining the function and role of a product should be given more attention the design process of the product. According to Sagot et al. [14] the process of product design requires a combination of approaches in social sciences and engineering sciences. The combination can respond to human physical factors which impact contribution larger in the design of a product. Wells believes that designers need to understand the needs of users before developing a design [15]. Technological developments are very closely related to ergonomics as they look to the harmony of human and operate the product when used together. Ergonomic is dependent on the ability of people. So the design of a product should be adapted to the physical characteristics of humans that takes into account the aspect of movement of human activities, views, thoughts and others in the current situation [16].

This paper focuses on a method that involves user and manufacturer perception towards the design and ergonomic features which are in line with Malaysia's identity in order to establish a successful new idea in the development of conceptual design for sofa in Malaysia. This paper acknowledges that the basic structure of a conceptual design for a product (including furniture products) consists of market products, technology, and consumer perception. However, this paper does not refer to a scaled observation of existing sofa and does not examine all the techniques and concepts that are applied on the product. Product design is rarely considered in the creation of entirely new products, but it is so in modifying existing products to the level of the most efficient and perfect [11].

## 2 Research Methodology

This paper has developed a method of classification as an important tool in the development of furniture design including public participation in the design process. A questionnaire survey was developed in order to identify the perception of sofa makers and consumers related to ergonomic design and comfortability of sofa. The respondents were randomly selected in the vicinity of industrial and small entrepreneurs in Kelantan. Besides, the respondents were also selected from the government and private agencies for consumers' perception. It involves 30 respondents in order to identify the perception of sofa makers and consumers on the size and material specifications to suit the needs of today's design of ergonomic sofa. To emphasize, public participation can create a sense of ownership and provide a better understanding of the specific local context. Specifically, it is able to

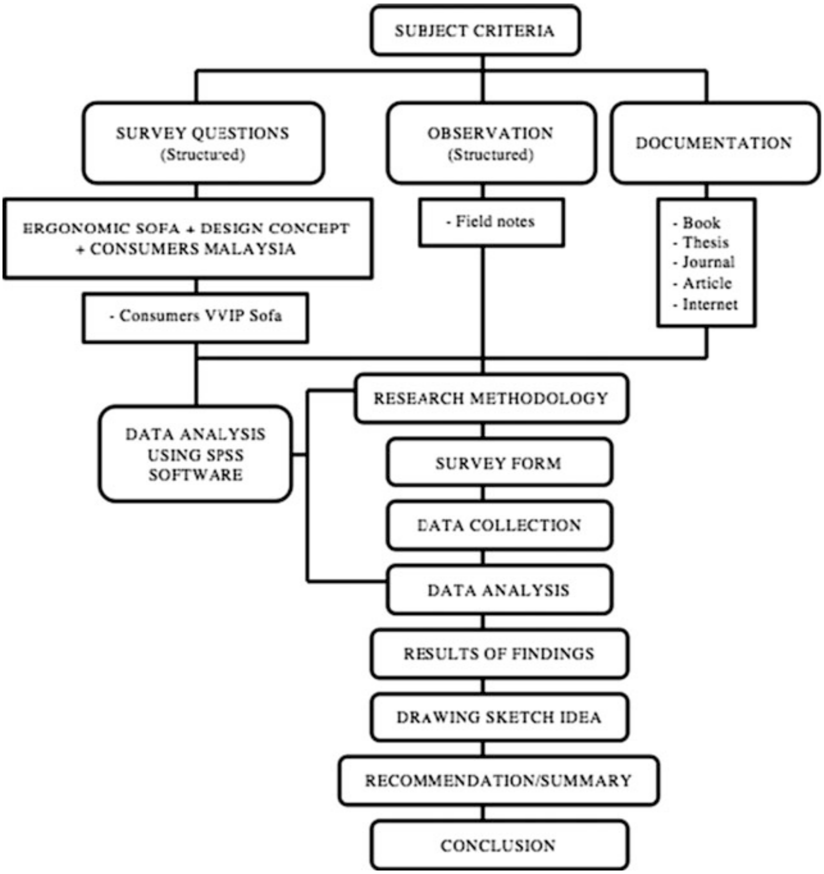


**Fig. 1** Flow chart of the research methodology used in this study

reflect the ideas of society in Malaysia [17] in terms of sofa preferences. New products may be useful to new users, but not to the current users who have been using and evaluating the performance of the appliance, which is held from the point of functionality and comfort. Normally, researchers just look at the potential of products, but in general the current user needs are addressed as they are more experienced with evaluating the practice and function of existing products [18].

### *2.1 Figures Development of Design Methods*

**Questionnaire survey**. The study has developed a questionnaire to be distributed to existing sofa makers around the industrial and small entrepreneurs in Kelantan, involving 30 respondents to identify the perception of sofa maker regarding the size specifications and requirements in the development of ergonomic sofa design nowadays. Researchers also have developed a questionnaire to be distributed to sofa users from government and private agencies in Kelantan, where 30 respondents have been involved in identifying the user's perception of the needs in development of the conceptual design of ergonomic sofa. Additionally, unstructured observations, such as photos and notes have also been used to record relevant data from the field. Figure 1 summarizes the methodology adopted in the study.

## 3 Results and Discussion

### *3.1 User's Perception of Ergonomic Requirements*

The feedbacks gathered from the questionnaire survey conducted among 30 sofa users that involved employees from both the public and private sectors. The questions include those that represent the concept of sofa, the general characteristics of sofa, and the color, texture and price estimates of sofa. Overall results of data analysis based on sofa user preferences can be summarised in Table 1 as follows.

Table 1 also highlights the preferable attributes of a sofa based on the findings from the consumer survey. Based on these identified preferences of sofa attributes by the users, a basic conceptual design of an ergonomic sofa can be sketched as in Fig. 2.

Figure 2 shows that the factor of human consumption is closely related to a new design. This is the reason why consumer's perception should be taken into account in the development of a conceptual design of a product. The aim is to understand what is required in today's market and to collect data which is then interpreted into the specification request. Specification demands consumer perception as a guideline in the process of this invention. This should be followed by the incorporation of innovative idea. This paper emphasizes on the consideration of ergonomic features for an innovation in the development of a conceptual design for sofa. Development

**Table 1** A summary of the results from the questionnaire survey and important sofa attributes for the conceptual design consideration

| Overall result analysis consumer | | | Percentage (%) | Design need proposal |
|---|---|---|---|---|
| Sofa Concept | Modern | | 50 | ✓ |
| | Contemporary | | 20 | |
| | Classic | | 3.3 | |
| | Executive | | 26.7 | |
| General features of sofa | Arm rest | Yes | 93.3 | ✓ |
| | | No | 6.7 | |
| | Back rest | Yes | 100 | ✓ |
| | | No | 0 | |
| | Head rest | Yes | 83.3 | ✓ |
| | | No | 16.7 | |
| | Leg rest | Yes | 70 | ✓ |
| | | No | 30 | |
| Basic colour scheme | Black | | 36.7 | ✓ |
| | Brown | | 16.7 | |
| | Blue | | 6.7 | |
| | Peach | | 13.3 | |
| | Orange | | 3.3 | |
| | Red | | 10 | |
| | Gray | | 13.3 | |
| Basic material | Leather | | 33.3 | ✓ |
| | Tender | | 0 | |
| | Velvet | | 20 | |
| | Velvet Blue | | 10 | |
| | Cloth | | 3.3 | |
| | Orange | | 6.7 | |
| | Red | | 10 | |
| Basic price range | Rm5000 and below | | 56.7 | ✓ |
| | Rm5,001 until Rm8,000 | | 36.7 | |
| | Rm8,001 until Rm12,000 | | 6.7 | |

of ergonomic design is a creation of new design development where several methods have been identified based on the perception of consumers in the process of upgrading the existing sofa chair in line with the needs and preferences of Malaysian users. This should also be followed by a consideration of the target consumers' ability to purchase. This is also important if the marketability of an ergonomic sofa is to be addressed in the Malaysian context.

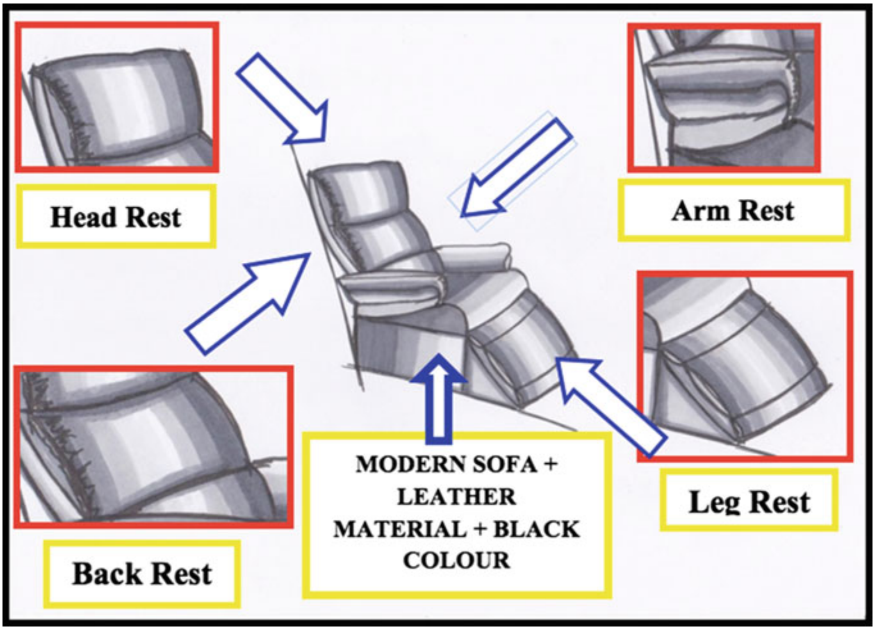


**Fig. 2** A sketch of the conceptual design of an ergonomic sofa based on the user preferences

### *3.2 Manufacturer's Perception of Ergonomic Requirements on Sofa Design Malaysia*

Apart from that, for the manufacturer perception, sofa makers feedback was gathered from a questionnaire distributed among 30 people that are involved in the sofa making industry and small entrepreneurs of sofa makers. The survey has focused on typical dimension of a sofa, type of material, sofa manufacturing process, the application of technical drawing and the perception of sofa makers about sofa making. This section presents the results and discussion on eight dimensions (A–H as in Fig. 3) related to sofa design.

Tables 2 and 3 summarises the results of the overall dimensions of conventional and basic specifications of materials for ergonomic design obtained from the sofa makers as the respondents. Sponge sofa wraps around the frame plays a key role in determining the level of comfort in the ergonomic design of the sofa. In addition, the material used is also very important to give the impact of changes to the common dimensions such as thickness of sofa span and span type used. However, the basic specification of sofa framework needs to be adapted with materials that will be used to get a perfect ergonomic design.

Furthermore, based on the final result in Tables 2 and 3 it can be said that the factor of human consumption is closely related to ergonomic design. This is because the perceptions of sofa makers are included in the process of designing a

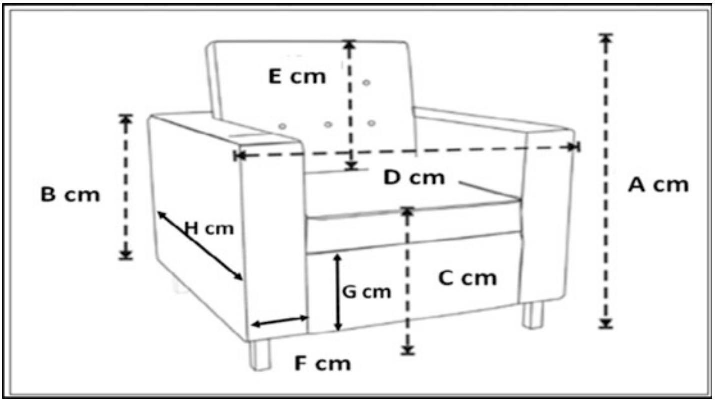


**Fig. 3** Eight dimensions (A–H) of sofa design

**Table 2** Overall results of conventional dimensions

| Frequently Dimension | Space (cm) |
|---|---|
| A | 100 |
| B | 50 |
| C | 52 |
| D | 50 |
| E | 58 |
| F | 58 |
| G | 25–26 |
| H | 78 |

**Table 3** Overall results of materials specification for basic ergonomic sofa design

| Type of Material | | Sofa makers (%) |
|---|---|---|
| Frame | Plywood | 50 |
| Spring system | Eight-way hand tied spring coils | 50 |
| Fundamental sponge | High density polyester sponge | 70 |
| Middle sponge | High density sponge | 50 |
| Wadding | High density sponge | 70 |
| Natural fabric | Leather | 90 |
| Synthetic fabric | Polyester | 50 |

product. The aim is to understand what is required in today's market from the collected data that is then interpreted into the specification request. In addition, basic specifications are followed and the use of quality materials are combined and developed into an ergonomic sofa design. At the final stage, ergonomic sofa design is developed into a final product specification and by translating all the important details so that the product is marketable. This design was developed by taking into account the perspective of sofa makers to produce a new ergonomic sofa design that is suitable for use in Malaysia.

## 4 Conclusion

This paper has proposed to create a number of methods in the design and ergonomic features which are consistent with Malaysian identity. This is important in order to establish a successful innovative idea in development of conceptual design for sofa with Malaysian identity. The researchers also give thought to the basic structure which consists of market products, technology, and perceptions of sofa makers and consumers for product improvement process. This is important in the implementation of the product improvement process. In relation to innovative idea, current furniture industry in Malaysia should consider ergonomic factors in developing the conceptual design more seriously in order to ensure that the end product is as perfect as possible. Specifically, factors that relate to concept of sofa, general features, basic color scheme, basic material and price range should be considered in the development of the conceptual design. Therefore, to ensure product excellence, ergonomics aspects need to be considered to be in line with the need and tastes of consumers. Accordingly, it will give a major implications in the development of ergonomic design to improve the quality of sofa productivity in the furniture industry in Malaysia.

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# Using Temporal Representations for Understanding Complex Interrelationships for Mission Planning

**Jennifer Danczyk, Stephanie Kane, Drew Housten, Martin Voshell, Ryan M. Kilgore and Chris Hogan**

**Abstract** The ability to analyze, recognize, and plan for operational events—i.e., patterns of change over time—is a critical component of effective situation assessment within the military. Military planners use time when faced with creating, comparing, and deciding on complex planning and re-planning decisions. One way to intuitively convey changes in time based information to planners is with the use of temporal representations, particularly timeline visualizations. Timeline visualizations have been a very popular method in the past because of their ability to provide a clear representation of the causes and effects that occur throughout mission increments which supports planners with re-planning for new events. In this paper, we discuss our unique design concept with using multiple timeline visualizations as a way to support military planners with understanding the complex interrelationships that occur when predicting the timing and availability of mission resources as well as analyzing the effects to unforeseen events. We also discuss future design directions that will incorporate user feedback to improve the system's usability and better visualize these interrelationships between planned actions.

**Keywords** Temporal representations · Military planning · Visualization · Situational awareness

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## 1 Introduction

The ability to construct robust plans that account for dependencies across elements and foreseeable events is a critical skill in many industries [1]. For practitioners, event recognition helps businesses optimize tasks, schedule staffing load, and manage resource constraints across time to effectively conduct project management strategies and perceive problem situations. The timing of past and current events can also shape the outcome of future events. Thus event recognition is critical for supporting re-planning activities to increase the robustness and resilience of developed plans. An important component of a well-constructed plan is its capacity to alert users to critical future events to allow them to preemptively account for additional needed resources. For example, a project manager may be aware of a complex deliverable that needs to be executed within the next several months. Having this vision ahead of time allows them to add additional staffing to the project to increase the deliverable's chance of success. A well-constructed plan also allows the user to track the history of past events and predict changes to future events. For the same example, the project manager could become aware that a past project deliverable was late by several weeks. Since that deliverable was late, they are aware that subsequent deliverables will also be late and can begin to strategize ways to correct the project's scheduling or create a new plan that meets a set of redefined project needs.

Within the military domain, planners, specifically those in command and control (C2) environments, are faced with a daunting task of organizing and predicting the timing of planned mission tasks and actions. These plans involve analyzing time-based interrelationships between multiple assets (e.g. military vehicles, weapons, warfighter deployment) and provide complications in maintaining situational awareness while executing planning tasks in a dynamic mission environment. In addition to managing these complex time-based relationships, military planners must comprehend the downstream effects that evolve throughout the mission. To be successful in such applications, effective support tools must go beyond presenting instantaneous state values, and must capture and present key event information and provide awareness of how that interruption may negatively affect other assets' plans. For example, a submarine may have a specific set of tasks assigned to them during a mission but a pop-up threat may unexpectedly appear, causing them to loiter below surface for an amount of time to maintain their stealth. This unplanned action of loitering may cause downstream effects to other sequential activities that deviate from the original plan, causing the planner to re-assign new tasks at different times to meet the overall mission objectives.

One way for military planners to maintain a high level of situational awareness of planning and re-planning is with temporal representations. These types of representations are useful due to the ability to easily view historical as well as future trends of information from the time-based perspective [2]. By providing this medium of information, the user is able to analyze interrelationships between planned units. Temporal representations are common in other domains that require a heightened sense of analyzing relationships of planned actions such as healthcare, where different regions of qualitative data (e.g. low, medium, or high patient temperatures) are displayed with color change [3]. In the construction industry, temporal representations have been used to show how a plan relates to segments of the anticipated final product [4]. Specifically in the military, temporal representations have been used to create a link temporal and geospatial display perspectives while showing the relationships between separate planned actions [5, 6].

The current work leverages recent cognitive engineering research on event detection and interpretation to explore multiple unique design concepts that support high-priority planning tasks [7, 8]. We discuss general decision making challenges to using temporal representations for planning tasks. Next, we describe our approach and the benefits of using timeline visualizations as a specific temporal representation for mission planning. In this current effort we have created multiple timeline views to encode a variety of tasks along with hard and soft constraints between planning activities. This approach also shows the effects of violating these constraints may have on the overall mission plan. In one view, the decision maker can infer the overall plan effects by manipulating actions for separate vehicles. The change in effects from the original mission plan are shown in an adjusted mission plan and gives the planner awareness of the time lapse between the adjusted actions. While timeline visualizations provide multiple benefits, there are also challenges such as finding appropriate ways to encode multiple semantic data categories (e.g. different vehicle task actions, types of vehicles) in a limited space without increasing cognitive overload. Military mission planning involves choosing resources based on specific platform characteristics, mission availability, and relevance to overall mission objectives. There are often multiple choices when selecting an optimal plan, which is complicated in a dynamic and fast-paced environment. In such an environment, military planners need the ability to select an optimal resource plan and monitor any changes as the mission progresses. To explore this, we discuss in detail our design concept of providing the planner with multiple timeline options containing different resource constraints. Based on design reviews with representative users, we conclude with a discussion of future design directions that incorporates user feedback to improve system usability and better visualize these interrelationships between planned actions.

## 2 Ease of Use and Challenges of Temporal Representations

Temporal representations are a popular way to visualize changes that occur to various information types over time [2]. Another benefit to this representation is the ability for a user to view emergent patterns over that time. In other words, past system states can determine current and future system states which allow the user to choose appropriate actions [9]. While there are a variety of different temporal representation design techniques, the use of timelines provides a familiar, analogical visualization to a user by mapping information sets from left to right. For military planning interfaces in particular, the use of timelines presents an opportunity to increase the interface's visual momentum by integrating information across separate displays [9]. For example, the direction and longevity of a scheduled task for a military vehicle can be incorporated within the planning interface's geospatial view to provide the planner with enhanced awareness of the vehicle's past, current, and predicted future location. Timelines can also incorporate a long-shot design strategy, where lower level information can be organized coherently to show how they relate to separate relationships between data (i.e. how different sets of lower level information relates as a combined state as well as how the different sets relate to each other) [9]. An example of this is by showing a variety of vehicle tasks that are performed at different times as separate visualizations and then combining them together on as an overall event.

Along with the benefits of using timelines to portray planning information to a user, there are some challenges can occur when using this design with multiple categories of information. When multiple categories of information are represented on a one-dimensional representation of time (i.e. a single timeline), there is a chance of data overload occurring. One solution to this could be to separate the information across multiple timelines to decrease the complications of viewing multiple encodings of data together. However, viewing a large quantity of data within a larger space may increase the chance of parallax (i.e. the effect of the position or direction of an object or information appearing to differ when viewed from different positions) causing increased confusion to the user when making decisions.

In past efforts, we have tried to combat this problem of defining interlining relationships between key temporal constraints for decision makers in Air Operations Centers (AOCs). Interactive timeline representations were developed to assist decision makers in not only evaluating their current planning environment but also help them form decisions based on their understanding of the evolving situation at that moment [5]. We have also used timeline design techniques while assisting managers at Army training facilities in understanding the past, current, and predicted environmental states of training grounds, thus increasing their awareness of needed execution of mitigation exercises. Our current approach shows the increase of cost over time for mitigation for a selected amount of ground contaminants. This can help to inform the facility manager of which areas of their training facility that are in need of contaminant removal over others as well as provide a mapping to the planning of mitigation [6]. This effort is similar to this strategy as it uses multiple forms of timelines for individual contaminants to showcase a variety of mitigation strategies.

## 3 Current Approach

Our design goal is to develop tools for military planners that create awareness of the relationships and downstream effects for planning timed activities during a mission with a developed set of visual encodings (Fig. 1).

There are three parts to our design effort (shown in Fig. 2). We show a series of separated timelines for multiple vehicles with encodings of individual activities for each of the six vehicles (bottom portion of Fig. 2). Our overall mission event timeline place the individual vehicle activities on a single timeline view while the adjusted mission event timeline shows the timing effects of surpassing any of the hard planning constraints (top portion of Fig. 2). In Fig. 3, hard planning constraints are represented by the vertical, thick, black line and advise the planner that an event should not occur past that specified time. A hard constraint can be defined as an action that must be completed by a certain time in the mission plan. In comparison, a soft planning constraint provides the planner with an acceptable time range the action should be completed, but if it is not, the plan will not falter. Having soft planning constraints offers options to the planner of when actions should occur; increasing the plan's flexibility and adaptability. Soft planning constraints are represented on the timelines with horizontal, gray rectangles.

For unseen events that happen in mission plans, it is crucial for military planners to be aware of how their original mission plan may change if a hard planning constraint is violated. To allow this capability, we have provided the planner with a way to directly manipulate an individual vehicle's plans. In Fig. 3 the planning operator has selected "Vehicle 1" and sees an instance where an activity violates a hard planning constraint. The subsequent planned activities for other vehicles that are affected are shown individually by the white circles. The amount of time elapsed by those events due to the violation of the hard constraint of "Vehicle 1" is shown by the dashed circles. If the "new" event does not cause a critical violation from hard constraints it remains a gray dashed circle and the events that become violated turn to a red dashed circle. This enables the planning operator to be aware of not only how many events violate hard constraints but also shows which vehicles are

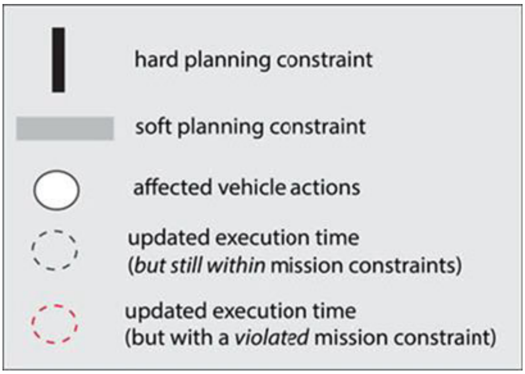


**Fig. 1** Legend showing the data encodings used in our timeline representations

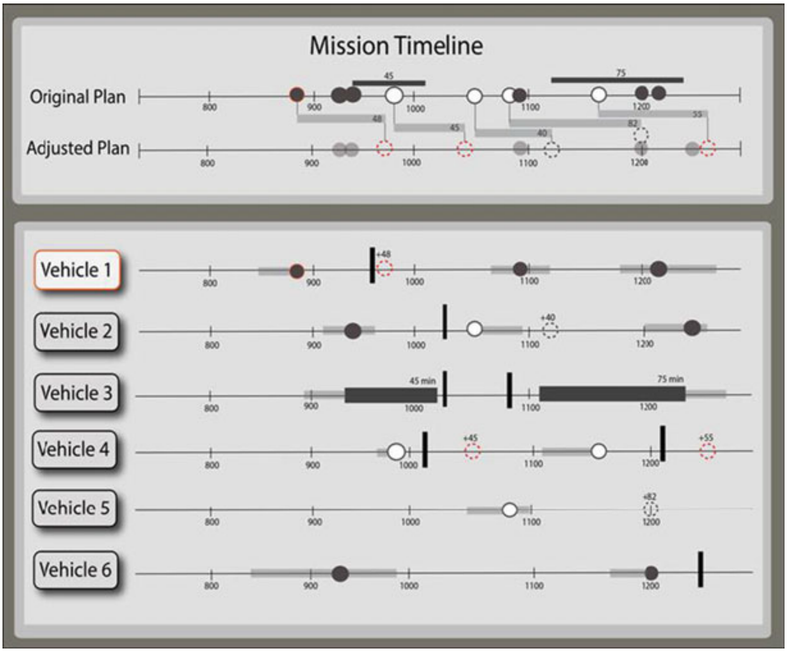


**Fig. 2** The overall timeline interface allowing the planner to view adjustments to the original mission plan and view different vehicle options

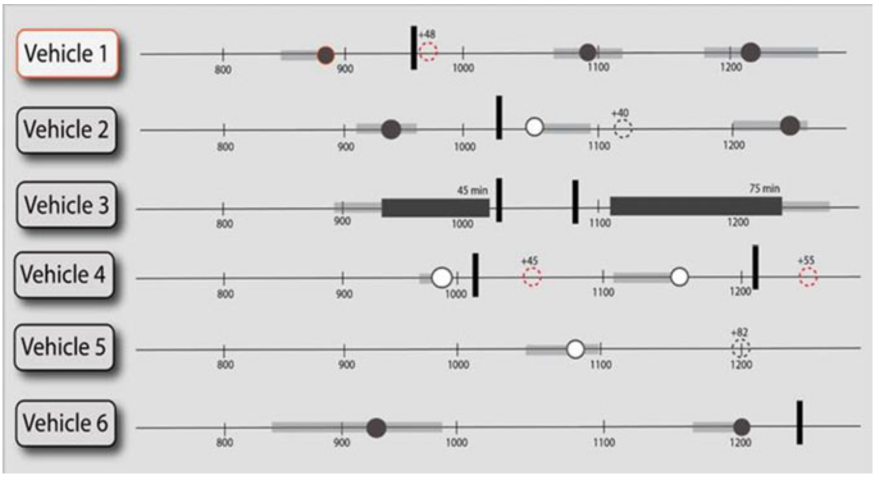


**Fig. 3** The separated temporal representations showing the user viewing the effect of violating a hard planning constraint. The effect planned actions are shown by the *white dots* and the *dashed circles* show their new temporal placement

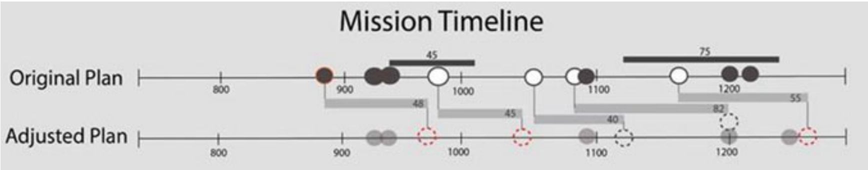


**Fig. 4** The overall mission timeline with the planner operato's original plan shown above with the adjusted overall plan shown below. The time elapsed between effected planning actions are displayed to give the user a way to compare alternatives

affected. For example, in Fig. 3, if "Vehicle 1" surpasses it's hard planning constraint by 48 min, "Vehicle 2", "Vehicle 4", and Vehicle 5" are affected. However, "Vehicle 4" is the only vehicle to violate any additional hard constraints.

In Fig. 4 the individual vehicle plans are displayed on the original plan of the Mission Timeline and any adjustments due to violations are shown on the adjusted plan. The affected actions are linked and show the timing differences between the original and adjusted plans. This view of the overall Mission Timeline helps the operator maintain awareness of changing relationships of the vehicle actions by incorporating an integrated long shot view.

## 4 Future Work and Conclusions

We will continue to iterate and expand the development of our timeline design strategies for military planning. In particular, we will investigate possibilities of integrating the interrelationships shown on the timeline views within a geospatial view to assist the planner with viewing the difference from the original and adjusted plan from a location frame of reference. Another area to investigate is how to provide an even greater amount of detailed information to the planner to influence their future planning decisions. An example of this could be allowing the planner to manipulate the actions of several different vehicles and provide them with recommendations of revised, optimal vehicle plans. We will also look to further define and develop other user interactions with the timeline component view.

Currently, we have not performed any type of formal user testing on how intuitive our temporal representation is to actual end users. We have started to refine our designs and determine the scope of information that needs to be included within our visualization by speaking with a limited set of representative users that work with unmanned vehicle mission planning tools. Their feedback was to expand on the current design by providing a greater amount of visibility on the detail of specific tasks and missions and the relationships between them (i.e. what task characteristics are best suited for a surveillance and intelligence mission). This would also provide a way to better understand the feasibility of conducting mission-critical tasks versus opportunistic tasks (i.e. an opportunistic task could be dropped if there was a greater need for a mission-critical task). Our next step for this effort would be to continue to iterate our designs while adding in new functionality and interaction that pertains to the current user feedback. After iteration we will implement this design into future military planning software and eventually perform quantitative and qualitative user testing to further perfect the interaction and representation.

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# Systemic Assessment of Human-Factor-Based Security Impact

**François Pérès, Carmen Martin and Vicente Gonzalez-Prida**

**Abstract** The paper deals with the use of a multicriteria approach based on a BOCR (Bonus Opportunity Cost Risk) analysis and the satisficing game theory to allocate a task to an operator from the contextual knowledge of its environment and the risk that may arise with respect to industrial safety. An application is given related to the allocation of tasks in the field of aeronautics maintenance by considering both performance an human factor impact on security.

**Keywords** Security · Human factor · Task allocation · BOCR analysis · Maintenance

## 1 Introduction

Though many studies have addressed the topic of safety systems or organizations, few considered the hierarchical relationship of propagation of events within a multi-layer architecture. It is the ambition of this work, which describes the first stage of a new approach, based on a 'U' model featuring the relationship between a system level (associated to a socio-technical system of production) and a component level (subsequently considered as an operator) both on functional and dysfunctional axis. The study concerns the implementation of a dependability approach and, more specifically the first step of a methodology allowing the assessment of the

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security measure resulting from the deployment of a new activity or related to the modification of the pace of an organization. Within this framework, the paper deals with the use of a multicriteria approach to allocate a task to an operator from the contextual knowledge of its environment and the risk that may arise with respect to industrial safety.

## 2 "U"-Based Approach Dependability Assessment

Carrying out analysis for the identification of dependability shortcomings requires the modelling of the mechanisms characterizing, in a top-down logic, the influence of the system solicitation on the solicitation/fault of an operator followed by a bottom-up analysis of the dysfunctional impact of this elementary level failure on the security of the entire system (Fig. 1). The deployment of this approach leads to several research avenues.

### 2.1 *On the Functional Axis*

1. *At System level*. The assessment of the level of security requires characterizing the severity of the environment which will be faced by the system studied. A qualitative and quantitative description of the influential factors must be made, leading to the **definition of a mission profile**.
2. *In the downward direction: System > Component*. The mission of the system profile is not that of the set of its constituent elements. For architectural, functional or location reasons, the solicitation of the system is therefore not

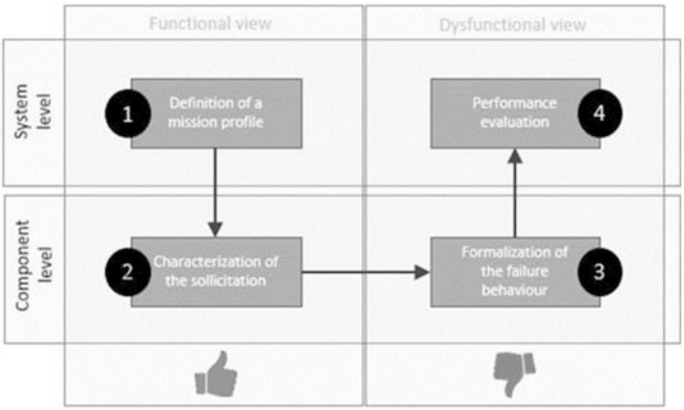


**Fig. 1** Principles of a "U"-based approach dependability assessment

identical to that of its components. Assessing the vulnerability of a component in terms of security (that is the potential bad decisions or errors of an operator) requires therefore the **measure of the influence of the system mission profile onto nomenclature lower level constraints** and in particular on the worker.

### 2.2 On the Dysfunctional Axis

3. *At Component level.* From knowledge of the operator mission framework and the corresponding stress which may result of it, it is then determined through an analysis of its dysfunctional behaviour, the errors likely to be committed and the results in terms of process-based dependent local injuries.
4. *In the upward direction: Component > System.* The human error rising process for the characterization of its impact from a security point of view at the system level will require aggregating information from analyses, combinations, and interpretation of the signals emitted by the most basic level.

From the conceptual modeling of the process of generation of a local fault attributable to the human factor, the methodology will seek to characterize the process of spread of its effects at higher levels of the organization in order to limit its security impact at the system level.

This combined approach will allow, in the top-down direction, to limit the risks by avoiding the human failures causes. Preventive analysis for the system specification or the choice of a type of organization definition will be established. In a bottom-up direction, the approach will lead to the reduction of the consequences of the human-factor based errors by the implementation of a fault tolerant robust system. Protection solutions based on organizational answers (control) or architectural measures (redundancy) will allow moving towards a more resilient system.

A methodology likely to support in a human context part of the "U"-based approach dependability assessment (UBADA) follows.

## 3 Human Resource Allocation

Vertical division of labour is based on separation between execution and intellectual work. Based on a scientific approach (posture and gesture decomposition and simplification, attribution of a run time to each elementary task), it determines the proper way to perform a task. The question of the optimal level of control in a situation of asymmetric information (moral hazard problem) is part of the agency relationship: the agency relationship models the relationship between the employer (which is called the principal) and the employee (which is called the agent). The moral hazard problem reflects the fact that the principal employer can hardly observe the level of effort made by the employee. The security/safety question is implicitly here introduced, as we will see later on [1, 2].

Horizontal division of labour deals with the question of specialization or versatility degree of the human assets. The optimal organization will require a cost and benefit analysis. The security/safety issue resulting of the activity breakdown must be considered. We propose at the following a methodology worked out to this end [3].

To select the best solution in terms of task allocation, the problem can be formulated as a multicriteria decision problem, where each worker is considered as an alternative with respect to the activity to be carried out and his own skills. Each alternative (worker) is assessed according to a set of indicators detailed on quantifiable attributes in order to estimate the achievement degree of the decision objectives (level of performance including the security level) by each potential employee. The different steps of the decision-making issue is introduced below:

1. Selection of objectives and indicators to measure their achievement degree.
2. Identification of potential alternatives.
3. Determination of a set of attributes allowing the evaluation of an alternative with regard to an objective through a pairwise comparison (objective, alternative) and a bipolar analysis (supportability/rejectability of the solution)
4. Evaluation of alternatives with respect of the objectives
5. Recommendations of an affectation of tasks per worker

A structuring framework based on the so-called BOCR analysis together with the AHP (Analytic Hierarchy Process) method is used. The BOCR analysis combines supportability/rejectability notions and uncertainty [4, 5] (Table 1). It consists in evaluating each alternative based on benefits (B), Opportunities (O), Cost (C) and Risks (R) [6, 7].

The choice of supporting/rejecting attributes can be made by considering the certain and uncertain parameters characterising a benefit/opportunity (cost/risk) of the alternative x on the achievement of objective y. Two sets are identified:

- $A_s^o$ stands for the set of attributes (involving benefits and opportunity) supporting the realization of objective 'o'
- $A_r^o$ represents the set of attributes (involving attributes of cost and risk) rejecting the realization of objective 'o'

The structuration of a decision problem can be supported by the AHP procedure by following a linear hierarchy going down from general to particular until achieving a level of operational criteria allowing the decision alternatives to be evaluated [8]. Figure 2 shows the model resulting from the combination of the BOCR analysis combined with the AHP procedure.

**Table 1** BOCR analysis factors

| | Certainty | Uncertainty |
|---|---|---|
| Supportability | Benefit (B) | Opportunity (O) |
| Rejectability | Cost (C) | Risk (R) |

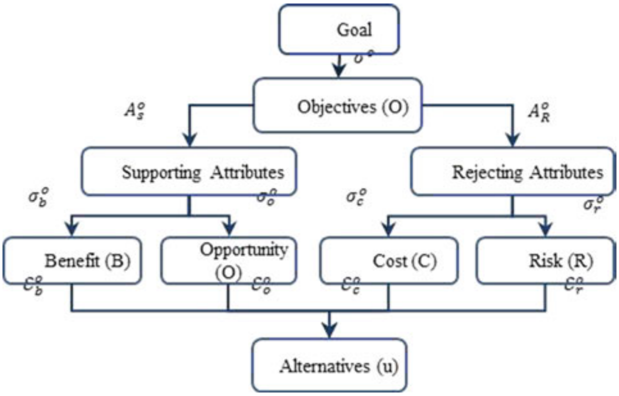


**Fig. 2** BOCR-AHP model structure

**Table 2** AHP pairwise comparing weights

| Qualitative scale | Numerical values |
|---|---|
| Likewise | 1 |
| Little more significant | 3 |
| Rather more significant | 5 |
| Much more significant | 7 |
| Extremely more significant | 9 |
| Intermediate values (compromise) | 2, 4, 6, 8 |

Assessing the decision problem using the AHP procedure [9] requires to assess the importance of the objective weight on the overall goal. Consequently, a comparison of each pair of the objective sets would lead to express the importance of objective '$o_k$' versus objective '$o_l$' to fulfil the overall decision goal [10]. Table 2 shows the scale used in the AHP procedure to the identification of a pairwise comparison matrix $\varphi^o$ where $\varphi^o(k, l)$ represents the relative importance of objective '$o_k$' versus objective '$o_l$' to the achievement of the overall decision goal.

Matrix $\varphi^o$ can be defined through a straightforward method grounded on the selection of a pivot objective to which the other objectives will be related. This leads to a consistent matrix. A pairwise comparison matrix M is called consistent whether it verifies [11, 12] $M(j, j) = 1, \quad M(j, l) = \frac{1}{M(l, j)} \quad and \quad M(j, l) = M(j, k)M(k, l).$

The relative relevance of attributes with respect of objectives $\sigma_\times^o$ can also be evaluated by attribute pairwise comparison taking into account the objectives for each attribute sub-set on every component of the BOCR analysis. The assessment of the alternative matrix considering different sub-sets of attributes $\mathcal{E}_\times^o$ factors where x stands for the different components of the BOCR analysis may be achieved by two ways: related to a given attribute, if the value of the alternative is arithmetical with $\mathrm{a_k(u_i)}$ the alternative $\mathrm{u_i}$ performance with respect to $\mathrm{a_k}$ then the pairwise comparison matrix $\varphi_\times^{\mathrm{a_k}}$ is obtained using Eq. 1 [13].

$$\varphi_{\times}^{a_k}(u_i, u_j) = \frac{\mathrm{a_k(u_i)}}{\mathrm{a_k(u_j)}}$$

If not, the matrix is calculated through the AHP procedure by considering the degree of performance of alternative $u_i$ versus alternative $u_j$ with regard to attribute $a_k$. The matrix is obtained through the following equation:

$$\mathcal{E}_{\times}^{o_j}(u_i, a_k) = \frac{1}{n}\sum_j \frac{\varphi_{\times}^{a_k}(u_i, u_j)}{\sum_l \varphi_{\times}^{a_k}(u_l, u_j)} \tag{1}$$

The bipolar type of the attributes considered in the AHP procedure makes it possible the final evaluation which consists in aggregating data for the representation of each alternative by both a single supporting measure (benefit and opportunity) and a single rejecting measure (cost and risks). Because of the attribute bipolar characteristics, we will use the satisficing game theory in the final evaluation.

The satisficing game theory is used when decision makers do not require the optimum solution (unlikely to be reached given the cognitive capacities and the amount of available information) but are happy with "good enough" alternatives [5, 14]. This means that the supporting contribution surpasses the rejecting one. Several sets characterized the game theory [15, 16]. The satisficing set $\Sigma q \subseteq U$ is the alternative set expressed by the following equation

$$\Sigma q = \{u \in U : \mu_S(u) \geq q\mu_R(u)\}$$

$q$ stands for the caution index. It can be adjusted with respect to the number of declared satisficing alternatives. However, there are many cases where some alternatives have better selectability and lower rejectability than others, it is clear that in such situation, the decision maker will want to choose these alternatives, the interesting set would be the set where satisficing alternatives are the best (without alternative better than them).

$D(u)$ is the set of alternatives that are strictly better than any alternative $u$ such as:

$$D(u) = D_S(u) \cup D_R(u)$$

where $D_S(u) = \{v \in U : \mu_R(v) < \mu_R(u) \quad and \quad \mu_S(v) \geq \mu_S(u)\}$

The equilibrium set $\mathcal{E}$ (made of dominant alternatives) is defined by:

$$\mathcal{E} = \{u \in U : D(u) = \emptyset\}$$

and the satisficing equilibrium set, the set $E_q^S$ is therefore given as shown below

$$E_q^S = \varepsilon \cap \Sigma_q$$

Selectability and rejectability measures are obtained through an aggregation process based on the satisficing game theory. Consequently, for an alternative $u_i$

$$\mu_{S(u_i)} = \frac{\gamma B(u_i) + (1-\gamma)O(u_i)}{\sum_{v\in U}(\gamma B(v) + (1-\gamma)O(v))} \tag{2}$$

$$\mu_R(u_i) = \frac{(1-\gamma)C(u_i) + \gamma R(u_i)}{\sum_{v\in U}((1-\gamma)C(v) + \gamma R(v))} \tag{3}$$

$$\text{with}: \quad X(u) = \sum_{o_j\in O}\left(\sigma^o\left(o_j\right)\left(\sum_{o_k\in A_\times\left(o_j\right)} \sigma_\times^{o_j}\mathcal{E}_\times^o(u_i, a_k)\right)\right) \tag{4}$$

# 4 Safe Task Allocation

## 4.1 Introduction to Industrial Safety and Human Factors

The human factor and organizational approach of industrial security consists in identifying and implementing the conditions that promote a positive contribution of operators and the collective industrial safety. Beyond the improvement in terms of production quality, the knowledge produced by this approach leads to a better understanding of what determines human activity and to an improvement of the working situations and organisation to bring together the conditions for a safe work.

## 4.2 Concept of Resilient System

Studies of hazard and risk analysis are made during the system design phase. The prevention of the risks is ensured by a series of barriers:

- technical system design (sizing, containment, security automation…);
- definition of operational procedures to keep the system within safe limits;
- training of operators to comply with the procedures;
- setting up of organization and management ensuring compliance with the rules;

Formalisms, rules, prepare the system against configurations that have been planned, and play a major role in the ability to deal with these situations [17]. It might occur however situations that have not been anticipated. The response of the system will then depend on the local resources availability and behaviour. The resilience of a system is "its ability to anticipate, early detect, and properly respond to variations in the functioning of the system in relation to the reference conditions with the aim to minimize their effects on its dynamic stability". The systemic safety showed that this resilience depends on two components:

- the capacity to avoid all foreseeable failures by formalisms, rules, automation, measurement and protective equipment, training for "safe behaviours", and a management ensuring compliance with the rules;
- the ability to anticipate, collect and respond to the unexpected failures by the organization. It is based on human expertise, the quality of initiatives, the working collectives and organizations, and a management careful to the reality of the situations and combining the different types of knowledge useful for security.

The extreme attention paid to formalize the response to foreseeable situations does not guarantee the relevance of the response to unforeseen situations. Worse, organizations that base their policy of security on the prescriptive formalism can be affected in their 'resilience', when a new or unforeseen situation arises [17]. Operation behaviours that contribute to security are not only the behaviours of compliance to the rules: they are also behaviours of initiative, which promote the careful exploration of the State of the system, the alert from dangerous situations, and the collaboration between actors that can contribute to security. All fits into the general framework of technical and organizational means, which more or less encourage these behaviours.

### *4.3 Principles*

At individual level the decision maker in charge of the allocation of people on the different tasks will have to:

- Consider human properties: body and human functioning have properties described by various disciplines (Physiology, psychology…). These properties are hardly adjustable, except in a limited way, by training.
- Characterize situations: behaviour is not only a result of personality or of operator training. The characteristics of the situations in which humans are placed lead to some more probable behaviours. If these behaviours are not desirable from the point of view of security, the only way to significantly reduce their probability of occurrence is to act on the characteristics of the situation.
- Take into account the variability.
- The system consists of variability of a much more fine-grained than what can be anticipated in the design. The operators present on the ground detect these changes and adapt their operating modes. Sometimes, security involves sacrificing the production: one initiates an emergency stop, shorten a procedure…
- Events planned in distinct procedure can be combined in a new way, or associated with unforeseen events. It is not possible, neither practically nor even conceptually, to imagine a meta-procedure covering all possible combinations.

The operators will develop an original response to this unusual situation, by mobilizing their individual and collective resources, and possibly refer to the hierarchy.

- Facilities are operated by persons who are not only different, but also variable, because of fatigue (muscular, nervous), events of life (conflict, mourning, failure…), biological rhythms (daily, monthly, seasonal, annual).

## *4.4 Case Study*

An application to the field of aircraft maintenance aimed at illustrating the methodological developments. It is indeed well known today and experts agree on the fact that accidents are often due to human errors made during maintenance [18]. Studies conducted so far to identify the causes of accidents or incidents, show that maintenance is called into question in 12 % of the cases, which puts it in second place just behind the faulty aircraft handling [19]. This figure is constantly increasing. Taking into account the human factor in the maintenance context of airplanes is crucial given the level of responsibility, the short deadline of intervention, the complexity and toughness of the environment.

The data used in the case study is available in (MIM 2013). The overall goal was to allocate a complex maintenance task to a worker among seven possible operators likely to perform the action. Performance and security objectives were fixed by the decision maker who elicited the indicators used to calculate the degree of achievement of objectives and detailed in quantifiable attributes characterizing the alternatives.

AHP procedure in the BOCR analysis framework allowed the assessment of alternatives through Eqs. (1) and (2). Table 3 gives the evaluation matrix for BOCR

**Table 3** AHP Evaluation matrix

| Objectives | $\mathcal{E}^{o}_{\times}$ | U1 | U2 | U3 | U4 | U5 | U6 | U7 |
|---|---|---|---|---|---|---|---|---|
| Economic objectives | $\times = b$ | 0.13 | 0.15 | 0.17 | 0.18 | 0.15 | 0.10 | 0.12 |
| | $\times = o$ | 0.08 | 0.12 | 0.24 | 0.04 | 0.20 | 0.26 | 0.06 |
| | $\times = c$ | 0.15 | 0.21 | 0.14 | 0.10 | 0.11 | 0.11 | 0.18 |
| | $\times = r$ | 0.10 | 0.14 | 0.17 | 0.15 | 0.14 | 0.17 | 0.13 |
| Environnemental objective | $\times = b$ | 0.13 | 0.14 | 0.16 | 0.16 | 0.15 | 0.13 | 0.12 |
| | $\times = o$ | 0.09 | 0.18 | 0.19 | 0.16 | 0.15 | 0.14 | 0.08 |
| | $\times = c$ | 0.03 | 0.19 | 0.11 | 0.36 | 0.07 | 0.06 | 0.15 |
| | $\times = r$ | 0.09 | 0.13 | 0.15 | 0.16 | 0.13 | 0.21 | 0.14 |
| Social objective | $\times = b$ | 0.16 | 0.14 | 0.13 | 0.18 | 0.11 | 0.14 | 0.13 |
| | $\times = o$ | 0.13 | 0.16 | 0.15 | 0.13 | 0.14 | 0.14 | 0.15 |
| | $\times = c$ | 0.09 | 0.04 | 0.09 | 0.52 | 0.10 | 0.08 | 0.09 |
| | $\times = r$ | 0.06 | 0.09 | 0.10 | 0.52 | 0.06 | 0.08 | 0.08 |

**Table 4** Selectability and rejectability measures ($\gamma = 0.5$)

| | U1 | U2 | U3 | U4 | U5 | U6 | U7 |
|---|---|---|---|---|---|---|---|
| $\mu_s(u)$ | 0.118 | 0.149 | 0.178 | 0.138 | 0.152 | 0.156 | 0.108 |
| $\mu_r(u)$ | 0.090 | 0.140 | 0.130 | 0.285 | 0.104 | 0.121 | 0.130 |

**Table 5** Alternative ranking

| Alternatives | U1 | U2 | U3 | U4 | U5 | U6 | U7 |
|---|---|---|---|---|---|---|---|
| Ranking | 3 | 4 | 2 | 7 | 1 | 5 | 6 |

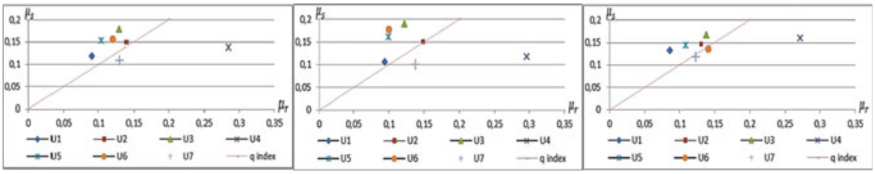

**Fig. 3** Graphical representation of alternatives with respect of γ

factors. The measure of selectability was calculated by relating for each alternative the contribution of benefit and opportunity through Eq. (2). Similarly, the rejectability measure was obtained by aggregating the cost and risk contribution of each alternative using (3). Table 4 summarizes the results. Table 5 presents the preferential classification order of the workers for carrying out the corresponding task.

Graphical representation is given in Fig. 3 by varying risk aversion indices ($\gamma = 0.5$, $\gamma = 0.2$, $\gamma = 0.8$).

## 5 Conclusion

This paper intended to address the problem of task allocation by integrating the security/safety issues associated with human factors. After having introduced a U-based approach as a general frame for dependability assessment and recalled the basic principles of labour division, a multicriteria method has been described. The AHP procedure combined with BOCR analysis have been proposed to solve this multi-criteria/multi-objectives decision problem. The satisficing games theory has been used. Indeed, because of the bipolar nature of attributes it appeared to be a relevant tool for the final recommendation process. The decision-maker nature has been also considered by taking into account the risk aversion index. The methodology was finally applied to the field of task allocation in an aeronautics maintenance context. The concept of resilient system has been recalled and in particular, the capacity of reinforcing the system safety by integrating the human-factor based dynamic context for the choice of the best assets. The main contribution of this study relies on the structuring framework enabling the evaluation of different alternatives.

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# The Relationship Between Vitamin D Deficiency Predisposition Among Healthy Young Individuals: A Few Considerations for Human Wellbeing and Overall System Performance

**Rosimeire Sedrez Bitencourt, Ester Farias de Souza and Carlos Alberto da Rosa**

**Abstract** Quality of life in the workplace considering workers' health is a defining factor allowing companies to remain competitive while their workers remain productive. However, in order to attain this goal, companies also need to consider a variable that is still not so much taken into account during job design, work organization, or even in the way their built structures are conceived. In this paper this variable translates into vitamin D, since it can prevent musculoskeletal disorders, and thus contribute to health maintenance. The method is comprised of bibliographic and exploratory research embodying a questionnaire based on empirical, scientific, and sociotechnical aspects. As for the main result, this study exposes a gap in terms of research and recommends investigation in different areas in order to contribute to the improvement of human wellbeing and overall system performance.

**Keywords** Musculoskeletal disorders (MSDs) · Vitamin D · Sociotechnical system · Job design · Work organization · Ergonomics

## 1 Introduction

The search for quality has been both a continuous and a priority action, allowing companies and organizations to remain competitive. In this respect, it is also necessary to consider the relationship between total quality and quality of life in the

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workplace concerning workers' health, since the costs of disease have an impact on the individual and on society, as well as on the company and its productivity. According to the Work Foundation, it is estimated that, by 2020, musculoskeletal disorders (MSDs) will be most damaging to the world's population, due to their impact on morbidity, on related diseases, leading to loss of productivity and the social exclusion of their carriers [1]. In Brazil, and all over the world, MSDs are the main cause of temporary, but also permanent work disability [2–4]. It is important to emphasize that the causes of these disorders are varied, according to [5], and research points out the preponderant responsibility of the work organization regarding the occurrence and aggravation of these disorders.

However, other variables may cause MSDs. According to [6], it is the case of vitamin D, which affects musculoskeletal health and its deficiency has been associated with an increase in muscle weakness, reinforcing absenteeism, low productivity, and dismissal from employment. As stated by Galvão et al. [7], this vitamin deficiency can be due to lack of exposure to sunlight, use of sunscreen, among others, but it can also be related to the way work is organized. Thus, the purpose of this research is to investigate a group of young healthy individuals at working age in order to determine their predisposition to vitamin D deficiency, and to identify whether it is possible, or not, to produce vitamin D in the human body as a result of the way the companies they work for are structured. Furthermore, the current situation is described in the light of the literature and recommendations for better health prevention are proposed, in an attempt to collaborate with company performance. Hence, exploratory research was conducted under the sociotechnical aspect in a university in Southern Brazil, which involved the participation of 215 undergraduate students. The study has three steps: (1) bibliographic research; (2) exploratory research; (3) analysis of results and recommendations.

# 2 Methodology

## *2.1 Bibliographic Research*

In order to achieve the proposed goals, the following databases were used in the bibliographic research: ScienceDirect, Emerald, Sage and PubMed. The search on these tools was based on the keywords "vitamin D", "disorder" and "work environment", respectively, and the search for the articles was limited to the months of August and September of 2015. No search parameters were defined/limited, like year or science field, for instance.

During the selection of the articles to be analyzed, only those related to MSDs were included due to the worldwide relevance of such diseases [2–4]. Therefore, the final result of the selection included nine articles published between the years 1999 to 2014. Additionally, the selected articles were classified into subject areas to facilitate further analysis.

## 2.2 Exploratory Research

To conduct the empirical data survey procedure, a single multiple-choice questionnaire was created, comprising open and closed questions (see Appendix). Undergraduate students residing in Curitiba—a city of great economic importance in Brazil [8] and characterized by subtropical climate [9]—completed the questionnaire in the classroom, and online, in October of 2015. The participation was limited to industrial engineering students enrolled in any year of college, including those who attend lectures in the morning or in the evening period. This limitation was necessary to ensure easy access to and questionnaire applicability.

The population included in the exploratory research was 945 students, of which 32.8 % (310) consisted in morning-period students and 67.1 % (635) in evening-period students. The sample available was 22.7 % (215) students, 45.1 % (97) female and 54.9 % (118) male.

The questionnaire was created based on a combination of three elements: (1) an empirical vitamin-D risk-analysis quiz adapted from [10, 11], (2) a scientific survey conducted among employees working in an office in a subtropical climate [12], and (3) a questionnaire based on sociotechnical aspects [13] comprising personal, organizational, technological and environmental questions. In addition to that, the study also made inquiries about the existence of quality of life programs in the companies.

With respect to the empirical quiz, two questions were omitted from the original questionnaire, since they did not apply to the sample. The first question omitted was about whether the respondent was over 50 years of age, and the second, whether he/she lived in latitudes greater than 35 degrees. As for the scientific survey, only the questions that resulted some positive correlation with the deficiency or insufficiency of vitamin D were added to the single questionnaire.

## 2.3 Analysis of Results and Recommendations

Bibliographic research included 167 articles, and the sample to be analyzed comprised 9 articles. During the analysis, the aim was to extract all the relationships between vitamin D, disorders, and work environment, in order to arrange them into a framework containing four sociotechnical subsystems (see Table 3). This considered, it was possible to identify gaps between the relationships and make recommendations.

# 3 Results

## *3.1 Bibliographic Research*

From the total of 167 articles comprising the bibliographic research, 96 were about non-musculoskeletal disorders and, therefore, were excluded; 55 were listed as not accessible by the university server; 6 had other content formats, such as references, indexes, and lists; 1 was duplicated; and 9 were selected for analysis.

As to the number of authors per article, the US was the country with more authors (13), followed by Sweden (3), and India (2). No Brazilian research could be identified among these publications. Regarding the databases, ScienceDirect was the one with the most results (5), followed by Sage and PubMed (2), and Emerald (1). Regarding publication years, it is observed in Fig. 1 that the cumulative quantity of articles within the scope of this study shows an increase over recent years.

As for classification of subject areas, 4 articles established a direct relationship between health and MSDs, 3 mentioned treatment methods, 1 referred to the location of facilities, and 1 mentioned public policies.

## *3.2 Exploratory Research*

### 3.2.1 Empirical Survey Results

Based on skin color, obesity, presence of pain in the bones or joints, muscle fatigue, use of sunscreen, time spent outdoors, consumption of fish or vitamin-D capsules,

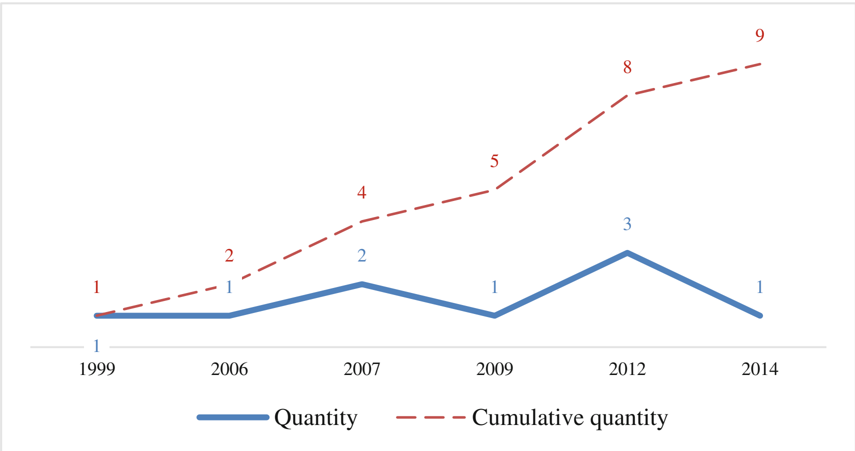


**Fig. 1** Number of publications per year

pregnancy, presence of liver, kidney, thyroid diseases or AIDS, drugs that hinder vitamin D absorption, smoking habits, sun protection with clothing or umbrellas, and sun tanning in the previous summer, according to a ranking established in the empirical survey [10, 11], it was possible classify respondents into four categories for the risk of having vitamin-D deficiency predisposition. The result obtained from n = 215 students was that 74.9 % (161) of respondents had a high, very high, or extreme risk, while 25.1 % (54) had low risk of becoming vitamin-D deficient.

### 3.2.2 Scientific Survey Results

As seen in the article [12], workers who had a positive history of non-melanoma skin cancer appeared to have a lower risk of 25(OH)D(25-hydroxyvitamin D) insufficiency in the summer. In this case, comparing this information with the results obtained in this study, it was observed that 99 % of respondents could have a higher risk of insufficient level in the summer period, according to Table 1. The second correlation was identified among workers who had never smoked; they showed less chance of having alterations in 25(OH)D than those who smoke or had smoked. Only 13 % of students could have an altered level of 25(OH)D for having smoked or for being current smokers. The third correlation points out that more than half the students (55 %) spend time outdoors for at least one hour in nonpeak UV periods (9:00 am–3:00 pm) on weekends, which was associated with an increase in the levels of 25(OH)D. As for the type of clothing, it also affects the levels of 25(OH)D; employees who wore full-length clothes during nonworking days in winter increased their risk of 25(OH)D insufficiency by 50 %. Comparing these results, 91 % of respondents in this study have an increased risk of 25(OH)D insufficiency during winter of 50 %.

**Table 1** Socio-demographic and general information on 215 respondents

| Socio-demographic/skin cancer risk/association with serum 25(OH)D levels | | N (%) |
|---|---|---|
| Sex | Female | 97 (45) |
| | Male | 118 (55) |
| Age (years) | 18–25 | 180 (84) |
| | 26–35 | 29 (13) |
| | 36 and over | 6 (3) |
| Current/past smoker | Yes | 27 (13) |
| | No | 188 (87) |
| Non-melanoma skin cancer | Yes | 1 (0.5) |
| | No/unsure | 214 (99.5) |
| Time outdoors weekend before 9 am and after 3 pm | 1 h or more per day | 119 (55.3) |
| | Less than 1 h per day | 95 (44.2) |
| | Unsure | 1 (0.5) |
| Long-sleeved clothing during winter | Yes | 196 (91) |
| | No | 19 (9) |

#### 3.2.3 Sociotechnical Survey Results

From the 215 students, 73.5 % (158) were already working, and so they were asked to answer the second part of the questionnaire, which includes sociotechnical aspects. With respect to working hours, less than 1 % work on night shifts.

Regarding job design and work organization, Table 2 indicates that the prevalence of responders (82 %) do not take breaks other than lunch or dinner. However, 72 % have the flexibility to set their own break schedule, the remaining 28 % said their supervisors, coordinators, managers, directors, or the HR sector, was responsible for determining the employees' schedule. Most of them (96 %) said they were happy with their working hours and break times. Regarding physical structure of the organizations, 89 % of respondents said that there were open spaces in the company where one can sunbathe. 70 % of students frequently have lunch at the company's cafeteria, where they take their home-cooked food, or eat the meals provided by the organization.

According to the respondents' perception, most of the cafeteria facilities (43 %) have no or few windows or in cases where there are many windows, they are closed. 80 % say that there are windows in the organizational environment that allow them to keep track of the sunlight, 54 % perceive the number of windows in relation to the total area to be sufficient, but most respondents (55 %) say that the windows are not opened well enough to allow direct incidence of solar radiation into the office or work environment.

Finally, considering the overall premises, 69 % of students stated that there are no transparent tiles allowing the passage of sunlight. As for personal benefits, most organizations (68 %) promote health prevention, wellness, or quality of life programs for their employees. From these initiatives, workout in the workplace and disease prevention programs account for 58 % of the results. As for health insurance, 93 % of respondents have private healthcare provided by the organization or purchased on their own. Finally, 64 % of students are unaware of their vitamin D level, 18 % say they are deficient, and 18 % have sufficient or above normal levels.

### *3.3 Analysis of Results and Recommendations*

#### 3.3.1 Contribution Based on Article Results

In terms of contribution, the articles analyzed are shown in Table 3, where all the excerpts involving vitamin D, disorders, and work environment were placed in each one of the columns representing the sociotechnical subsystems. It can be noted that the personal and work environment subsystems were the ones with more contributions, if compared to the job design subsystem, while the technological subsystem did not result in any contribution.

**Table 2** Work information on 158 respondents

| Sociotechnical system questions in the workplace | | N (%) |
|---|---|---|
| Sector of employment | Industrial | 111 (70.3) |
| | Other | 47 (29.7) |
| Working hours | Day shift work | 135 (85.4) |
| | Night shift work | 1 (0.6) |
| | Undefined | 22 (13.9) |
| Breaks (besides lunch/dinner) | Yes | 28 (17.7) |
| | No/unsure | 130 (82.3) |
| Flexibility to determine break time | Yes | 144 (72.2) |
| | No/unsure | 44 (27.8) |
| Open area at workplace (to sunbathe if possible) | Yes | 140 (88.6) |
| | No/unsure | 18 (11.4) |
| Happy with break time/office hours | Yes | 151 (95.6) |
| | No/unsure | 7 (4.4) |
| Lunch habits | At the company | 111 (70.3) |
| | Outside the company | 47 (29.7) |
| Meals are provided at workplace | Yes | 111 (70.3) |
| | No | 47 (29.7) |
| Company's cafeteria structure | Closed, without or with few windows | 29 (18.4) |
| | Closed, with many opened windows | 55 (34.8) |
| | Closed, with many closed windows | 39 (24.7) |
| | Not applicable | 35 (22.2) |
| Campaigns to promote health, welfare, quality of life | Yes | 107 (67.7) |
| | No | 51 (32.3) |
| Types of campaigns or initiatives | Labor gymnastics and others | 80 (37.2) |
| | Gym/sports | 35 (16.3) |
| | Illness prevention programs | 51 (23.7) |
| | None | 49 (22.8) |
| Health insurance | Yes | 147 (93) |
| | No | 11 (7) |
| Vitamin D level | Insufficient | 9 (5.7) |
| | Deficient | 19 (12) |
| | Sufficient | 29 (18.4) |
| | Unsure | 101 (63.9) |
| Windows at workplace to keep track of sunlight | Yes | 126 (79.7) |
| | No | 32 (20.3) |
| Windows allow direct sunlight into the office | Yes | 62 (39.2) |
| | No | 87 (55.1) |
| | Not applicable | 9 (5.7) |
| Enough windows considering the total room area | Yes | 86 (54.4) |
| | No | 67 (42.4) |
| | Not applicable | 5 (3.2) |
| Transparent tiles to allow sunlight radiation | Yes | 49 (31) |
| | No/unsure | 108 (69) |

**Table 3** Articles analysis and extraction under sociotechnical subsystem

| Article title | Personal subsystem | Job design | Work environment |
|---|---|---|---|
| Improving musculoskeletal health: global issues [10] | Medical students lacks understanding about MSDs, some institutions entitle this study as not required. There is an association of back pain with social status, education, sedentary work and crafts. There are discussions to eat a healthy diet containing calcium and vitamin D to prevent MSDs [10] | There are discussions to avoid repetitive activities to prevent MSDs [10] | There are discussions to modify the work environment to prevent MSDs [10] |
| An equation of health: Role of transparency and opacity in developing healthcare efficacy measures and metrics [11] | Traditional therapies recognize that the production of vitamin D through sun promotes bone formation, metabolic detoxification, improve lean muscle mass and stimulate wound repair. Vitamin D plays an important role in maintaining healthy cells as well as reducing the risk of formation of carcinogenic cells. The necessary 20 minutes of daily sunlight represents much more than what people actually take [11] | | |
| Chapter 5.6: Major public health problems—musculoskeletal disorders [12] | Measures that promote health should be taken continuously in the workplace from good prospects for health, good use of resources and high productivity. One example cited is to spend more time in outdoor location, get sun exposure to produce vitamin D [12] | | |
| Health inequality—determinants and policies [13] | | | The working environment (psychosocial and ergonomic) is one of the 12 determinants of social inequalities in health. The report “Future work environment in 2020” prizes for three issues: Psychosocial work environment, ergonomic influences and occupational diseases (including MSDs) due to the epidemiological level they arrived and their burden the world economy. One of the outcomes of these priorities focuses on |

(continued)

**Table 3** (continued)

| Article title | Personal subsystem | Job design | Work environment |
|---|---|---|---|
| | | | workplace design in order to ensure worker satisfaction and well-being including specific ergonomic improvements [13] |
| The link between vitamin D metabolism and sleep medicine [14] | The duration of daily sun exposure habits and the culture of using certain clothing as well as skin exposure are some factors that determine the vitamin D synthesis in individuals [14] | | The working environment (internal and external) is one of the factors that determine the vitamin D synthesis in individuals [14] |
| Morbidity pattern of the 27th Indian Scientific Expedition to Antarctica [15] | Vitamin D deficiency can be prevented even in areas with a shortage of sunlight, such as the Antarctic [15] | | The working environment in Antarctica is very challenging. The region has long periods of darkness, yet when explorers are working externally use sunscreen against ultraviolet rays because they burn easily [15] |
| Public health, wellness, prevention, and health promotion: considering the role of chiropractic and determinants of health [16] | Prevention, wellness and health promotion are neglected when compared to short-term treatment (antibiotics or vaccines). MSDs are preventable with healthy diet and exercise. However, health problems are treated only in advanced stages, for example, when there is already an osteoporotic fracture. Level of education is another factor observed when it comes to take in more nutrients and a better diet (including calcium and vitamin D) [16] | | Doctors of chiropractic should consider the work environment to positively impact the health of patients and community especially regarding the prevention of MSDs that account for significant occupational diseases [16] |
| Back pain: delimiting the problem in the next millennium [17] | Of all the MSDs, back pain is the most prevalent. Also, it would be linked to psychosocial factors [17] | Job satisfaction is an independent related backache variable [17] | Backaches are related to the work environment [17] |
| Physical disability due to musculoskeletal conditions [18] | Through the ICF framework (International Classification of Functioning, Disability and Health), various personal factors (stress, working conditions, socioeconomic status and diet) are associated with MSDs. The daily intake of calcium and vitamin D reduces the risk against MSDs, especially osteoporosis [18] | | Through the ICF framework, factors such as design, construction and technology of the public built environment are associated with MSDs. Empirical data on this category are scarce [18] |

### 3.3.2 Recommendations for Better Health Prevention

Personal Aspect: (1) for organizations that provide meals in their own cafeteria, we propose a daily balanced diet containing calcium and vitamin D, based on medical recommendations and considering the nutritional characteristics of the local population; (2) educate employees on the importance of staying out in the sun, sparingly, within the limits of scientific advice, conveyed by campaigns and disease-prevention programs; (3) disseminate across the company through internal marketing that sunscreen should be used sparingly in order to enable the production of vitamin D in the body; (4) stimulate employees to have annual vitamin-D tests done; (5) promote social events and business training outdoors, whenever possible; (6) approximate pure research conducted in universities to applied research conducted in companies with the purpose of establishing public policies focused on vitamin D supplementation in the foods that are most consumed by the local population.

Technological Aspect (lighting systems): (1) study the feasibility and return on investment of replacing traditional internal lighting systems by skylights that naturally lighten up the environment in the organizations. Consider what has been said in the study, that prolonged sunlight exposure has harmful effects on the skin [14]; (2) measure 25(OH)D levels in employees before and after the installation of technological systems that bring natural light into the internal environment; (3) conduct follow-up to check if there is a decrease in MSDs development after installation of the systems; (4) if there is a decrease, emphasize the savings resulting from this implementation along with productivity gains; (5) if there is no decrease, investigate if there are other factors that might be contributing to MSDs.

Technological Aspect (materials' technology): (1) study the possibility of developing a type of glass unable of filtering out UVB rays; (2) study the possibility of developing other materials to be used in lining or covering the facilities allowing UVB rays to pass through.

Job Design: (1) encourage employees to engage in workout sessions outdoors at times when there is the highest incidence of UVB rays; (2) encourage employees to take their breaks outdoors.

Working Environment: (1) recreation and rest areas should be placed in at least two areas: a closed and an open one, with the possibility of receiving direct sunlight radiation; (2) build dining areas so that solar radiation may be direct in indoor areas, including enough windows.

This list is not intended to exhaust the subject, but instead, it offers some suggestions of business and social interest.

## 4 Final Considerations and Discussion

This article aims at identifying structural, organizational, and personal conditions in young healthy individuals at working age with the purpose of contributing to the production of vitamin D. Among the principal results of the empirical research, 80 % of respondents who work do not take other breaks other than lunch or dinner, which could be conveniently used to sunbathe. This fact could be more likely due to personal or organizational reasons and less likely due to the environment, once 88 % of participants claim that the companies' premises provide enough open areas for sunbathing. Without taking other breaks, one still could produce vitamin D during mealtime or during working hours upon certain conditions. Regarding the first option, it is necessary to observe the lunch habits of the employees. In this research, more than 70 % eat in company cafeterias and 43 % of the cafeterias have no or few windows or have many closed windows. Therefore, in this situation, producing vitamin D is difficult, considering that glass windowpanes absorb the ultraviolet B radiation responsible for synthesizing the vitamin in the body [15]. As for the second option, it is also necessary to consider the layout, quantity, size, and type of windows in the workplace, mostly because they have to allow direct sunlight incidence into the environment. However, the results obtained for this question limited the analysis, since it was not specified in the questionnaire whether the incidence was influenced by glass.

Regarding the result for vitamin D deficiency predisposition obtained for n = 215, nearly 75 % of respondents have a high, very high or extreme risk, which was expected, since at least 50 % of Brazilian young individuals at working age live in the southern region and were found to be deficient according to [16].

Concerning the main results from the bibliographic research, six out of nine articles agreed that sunbathing or ingesting vitamin D are essentially associated with a healthy diet, and more so with MSD prevention. From the extractions included in Table 3, it was observed that few practical solutions have been proposed. This is due to the small number of publications on the subject at the time of the quantitative analysis.

It is also noted that the first publication addressing vitamin D, disorders, and workplace dated from 1979 in the four databases consulted, although the first article correlating vitamin D in the organizational context with MSDs dates from 1999. Considering that the theme has been the subject of discussion only in the last seventeen years, solutions to treat these disorders hardly exist or have not yet been investigated. Thus, this study highlights the importance of starting several other lines of research such as work organization, structures of the built environment, nutrition, law, new technologies, among others that could be investigated in order to identify performance losses reflecting on human wellbeing as well as on overall system performance.

## 5 Future Work

Given the importance of the theme addressed, it is our aim to validate the research by determining serum 25(OH)D levels through blood tests to confirm vitamin D deficiency in participants with higher predisposition.

In line with this research line, future work will consist of a parallel discussion about the classification of windows, tiles as well as other apparatus to be incorporated in the superstructure of the built environment as part of the technological subsystem in the field of macroergonomics. This discussion will redefine the concept of such elements focusing not only on illuminating the indoor setting, but also on increasing individuals' performance and generating health.

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## Appendix: Online and Paper-Based Questionnaire

| |
|---|
| (1) **Personal questions** |
| 1. What is your age? |
| 2. What is your gender? |
| 3. Do you have brown skin? |
| 4. Are you overweight? |
| 5. Do you feel muscle fatigue, bone, or joint pain? |
| 6. Do you use sunscreen to sunbathe? |
| 7. Do you rarely stay outdoors between 10 am–3 pm? |
| 8. Do you usually eat fish or take vitamin D capsules? |
| 9. Are you pregnant? |
| 10. Do you have AIDS or kidney, liver, thyroid diseases? |
| 11. Do you take any medication that affects vitamin D absorption (e.g. Xenical, Dilantin, drugs against tuberculosis)? |
| 12. Are you a current or past smoker? |
| 13. Do you frequently protect yourself from the sun with clothes or umbrella? |
| 14. Did you get a tan last summer (in case you have had vacations)? |
| 15. Have you ever been diagnosed with non-melanoma skin cancer? |
| 16. How much time do you spend outdoors on weekends, between 9 am–3 pm? |
| 17. How much time do you spend outdoors on weekends before 9 am and after 3 pm? |
| 18. Do you usually wear long-sleeved clothes during winter? |
| 19. At what time do you start and finish classes? |
| 20. Do you work? |
| (2) **In case you have answered positively the last question, please continue the survey** |
| 1. At what time do you start and finish work? |
| 2. What is the sector you are working for? |
| 3. Do you take other breaks other than lunch or dinner break? If so, please specify the time period |
| 4. Do you have flexibility to define your own break time? If not, please specify who is responsible for that in your company |
| 5. During break time is there an open area (where it would be possible to sunbathe)? |

(continued)

(continued)

| |
|---|
| 6. Are you comfortable with your office hours? If not, specify the reason |
| 7. Regarding your working lunch habits, which occur more often? |
| 8. Are the meals provided at the company's cafeteria? |
| 9. In case there is a cafeteria, which of the below is most similar to your company's? |
| 10. Are there initiatives to promote workers' health, wellbeing or quality of life? |
| 11. Considering the initiatives below, which ones are promoted by the company? |
| 12. Do you have health insurance? |
| 13. Regarding your vitamin D level |
| 14. Are there windows at your workplace that allow you to keep track of the sunlight? |
| 15. The windows in your office big enough to allow the sunlight to reflect directly into the work environment? |
| 16. In your perception, are there enough windows when compared to your office's total area? |
| 17. Are there transparent tiles in the company´s facilities that allow direct sunlight to come in? |

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# Part IV
# Ergonomic Design for Industry and Musculoskeletal Disorders (MSD's)

# Redesign of Work-Accessories Towards Minimizing Awkward Posture and Reduction of Work Cycle Elements in an Indian Shop-Floor Workstation

**J. Sanjog, Rajiv Lochan Baruah, Thaneswer Patel and Sougata Karmakar**

**Abstract** Indian plastic processing industry comprises of Micro, Small and Medium Enterprises (MSMEs). Manual labor and locally designed workplace fixtures are observed in shop-floor workstations. Aim of present research was to identify incidence of musculoskeletal ailments and awkward working postures among workers in the granulator workstation and propose design modifications from physical ergonomics perspective. Combination of research techniques comprising of questionnaire study, postural assessment tools, statistical analysis, digital human modeling and method study were utilized to accomplish the stated objective. Significant occurrence of body part discomfort was observed. Workstation accessories designs were not in accordance with recommended guidelines. Workstation design and work methods were found incompatible with worker's anthropometry and thus led to the prevalence of awkward working postures. Redesign of workstation accessories and subsequent modification of work methods, enabled improvement of working postures and reduction of work elements. Research methodology demonstrated in present study may be adopted by engineers/managers/supervisors in MSMEs towards implementing context specific human centric production systems.

**Keywords** Granulator workstation · Industrially developing countries · Manufacturing · MSMEs · Virtual ergonomics

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## 1 Introduction

Improvement in work satisfaction, productivity and workers well-being can be achieved only if workstations and work environments are designed in accordance with recommended guidelines put forth by scientific organizations and also conforming to natural laws of work. Ergonomic investigations and applications are mostly observed to be reactive in scenarios where less attention is given for man-machine compatibility while installing and commissioning work systems. Presently, computer aided digital human modeling and simulation technology has emerged as state-of-the-art technology for physical ergonomics evaluations [1]. Manufacturing tasks (repeated thousands of times a day) in standardized workplaces compel workers to adapt and thereafter result in incidence of musculoskeletal disorders/repetitive motion syndromes, etc. [2]. Industrially Developing Countries (IDCs) are characterized by heterogeneous array of cultures, people surviving in habitats of limited resources, poverty, under production and human labor power based functioning systems [3]. Therefore, application of ergonomics in IDCs should be related to the demographic region under consideration [3]. However, very few attempts had been made to apply ergonomics in an organized manner in Indian industries and lack of communication with other functional areas (production, design, safety and industrial engineering) are the major reasons for current negligible application of ergonomics in industrial practice [4]. Investigation (from ergonomics perspectives) in the manufacturing sectors is of utmost necessity to address challenges in workstation design and work methods in present-day Indian and IDCs scenario. Indian plastic processing industry consists of micro, small and medium enterprises [5] where less automation, prevalence of manual labor, locally designed implements and work place fixtures are usually observed in machine shop-floor. In present research, a granulator workstation (also known as scrap grinder) was examined based on a ergonomics research methodology comprising of questionnaire study, statistical analysis, postural evaluation tools, work study and digital human modeling technology in order to effect suitable design modifications for enhancing worker's postural comfort and minimizing risk perceptions of working postures.

## 2 Methodology

A survey was conducted involving four injection-molded plastic furniture manufacturing factories in Kamrup district of Assam state in India. Among different workstations in these factories, granulator workstations (which grind rejected/defective finished goods and used plastic products collected from the open market, into plastic granules for reuse in the production process) were selected to perform ergonomics investigations as these were found in all the factories surveyed, and sufficient scope for design interventions were noticed during initial observations.

Loading of products into these granulator machines for grinding were being performed manually. Workers employed in the granulator workstations were male only. Healthy adult male workers were selected as participants as per the following pre-set inclusion criteria—similar age, weight, standing height and work experience (minimum one to maximum five years of uninterrupted work in the present occupation); and no medical record of any chronic disease and/or incidence of accidents/injuries which may results in pain/body-parts discomfort. Workers with work experience of more than five years were rarely present in any of the factories. Standardized Nordic Questionnaire (SNQ) [6] was used to investigate prevalence of musculoskeletal troubles and to identify suffered body parts. Ten workers from the granulator workstations volunteered as participants. Workers from granulator workstations were considered as the experimental group whereas fifteen individuals with similar demographic characteristics but involved in different activities (administrative and supervisory occupations and having more than one year of continuous work experience) were selected to constitute the control group for comparison of incidence of symptoms of musculoskeletal ailments (ache, pain and discomfort) in body parts between these two groups. Information regarding age, work experience was gathered from an interview followed by direct measurement for standing height and weight. Sample sizes of the experimental and control group were small. The collected data sets did not follow normal distribution. Mann Whitney U test and Chi square test were employed to analyze and interpret collected data using SPSS V.20.0 (IBM, USA) software. Continuous videography was not permitted by factory managements. Therefore work activities performed in the granulator workstation were observed at the factory site and photographed for investigations. Mechanical design feature of DELMIA (V5R19) digital human modeling software was used to generate CAD model of the existing granulator workstation based on the measured dimensions of the granulator workstation at the factory site.

Due to non-availability of Indian anthropometric data base of factory workers employed in plastic processing industry, civilian anthropometric database of adult Indian male population [7] was utilized to build digital human models for virtual ergonomics assessments. Smallest, average and largest dimensional adult Indian male population were represented by 5th p, 50th p and 95th p digital male human models (manikin) respectively. Comfort angles were imparted to the digital human models. Comfort angles for different body segments were adopted and suitably adjusted from published literatures [8–10]. Uncomfortable range of movement was given ‘red’ color while ‘green’ color was used to represent the comfortable range of motion of body segments. Proper interfacings of granulator CAD model with manikins featuring selected working postures were achieved using ergonomics design and analysis feature of DELMIA software. Existing workstation and work activities were evaluated using all three representative manikins (5th p, 50th p and 95th p) for identifying postural load.

Ovako Working Posture Assessment System (OWAS) [11] and Rapid Entire Body Assessment (REBA) [12] were used to identify poor posture towards determination of corrective action to be taken. The classification under OWAS methodology to identify poor posture and determination of action categories based on momentary observations was performed as continuous video recording was not permitted. Therefore evaluation of relative proportion of postures in terms of time in OWAS was not possible. As there are some limitations in OWAS technique, REBA technique for postural assessment was used subsequently for obtaining proper inferences. Compressive forces generated in L4-L5 lumbar spine (due to mass of body and load acting on hand and trunk) have an allowable limit (safe cut off limit) of 3433 N and maximum permissible limit of 6376 N as recommended by National Institute of Occupational Health [13]. A safe limit of 500 N with 1000 N as maximal permissible limit was suggested by University of Waterloo ergonomic research group towards joint shear [13]. Compression and joint shear values of 4th and 5th segments of the lumbar region were evaluated before and after making suitable alterations in workstation design and work methods. Method study which concerns with analyzing the movements of human body with the aim of eliminating unnecessary motions, minimizing fatigue and enabling better synchronization of efforts [14] was also applied in present study. Operation chart (based on observations of worker performing the job) for hand activities (left and right) is a simple and effective aid for scrutinizing a particular operation, if the work can be visualized in terms of elemental motions of hands [15]. Two symbols are used for constructing the operation charts, namely, a small circle for indicating transportation (moving hand to grasp an object) and a larger circle to signify actions like grasping, positioning, using, or releasing an object/article [15]. Left and right hand operation chart was used to understand, scrutinize and record existing work activities for comparisons with anticipated work activities after modification of work station and work method. It was observed that the work elements in a typical work cycle were not performed in same sequence consistently by the workers. Workers were noticed taking rest pauses, keeping retrieved parts (from stack) on machine slot or on working platform before conveying it into granulator. Recording time aspects of work elements with irregular cycles (irregular work pattern) is beyond the capacity of any observer to observe and record without external aids like videography [16]. In present investigation, study of time aspects was not feasible as continuous videography was not allowed by factory managements. Granulator is auxiliary equipment and it does not immensely affect time constraints of the main production process using injection molding machines. Hence, time study concerning work activities for work measurement was not considered in current research.

## 3 Observations from Existing Granulator Workstation

The work activities in the granulator workstation (represented by selected working postures) are shown in Fig. 1.

Comparison using Mann Whitney U test of variables between the experimental and the control group indicated that there are no significant differences between workers of the granulator workstations (experimental group) and control group


**Fig. 1** Selected working postures in granulator workstation

(Table 1). This indicates that participants in the experimental group as well as the control group were of similar age, standing height, and weight and work experience.

The distribution of incidence of musculoskeletal troubles (during last 12 months) is shown in Table 2. Among 15 participants of control group, number of participants suffering from one or more body parts discomfort was 5 whereas all 10 participants of experimental group were suffering. Statistical analysis ($\chi^2 - 12.150$, $p \leq 0.05$) revealed that significantly more number (in terms of percentage) of participants was suffering from body-parts discomfort in experimental group than control group. Although workers of the granulator workstation were of similar characteristics (age, standing height etc.) as of the control group; higher prevalence of musculoskeletal ailments in various body parts among granulator workstation workers might be due to differences in occupational activities which in turn are influenced by working posture, work methods, manual load handling and workstation design.

**Table 1** Comparison of demographic characteristics between experimental and control group variables

| | Units | Experimental group | | Control group | | Comparisons (Mann Whitney U test) |
|---|---|---|---|---|---|---|
| | | Granulator workstation (GW) (n = 10) | | Other employees (CG) (n = 15) | | GW versus CG |
| | | Mean | SD | Mean | SD | |
| Age | years | 27.1 | 2.5 | 25.4 | 2.5 | NS |
| Weight | kg | 61.6 | 2.9 | 58.7 | 5.3 | NS |
| Stature | cm | 164.7 | 6.1 | 162.7 | 7.4 | NS |
| Experience | years | 2.0 | 0.8 | 1.8 | 0.7 | NS |

*NS* no significant difference ($P > 0.05$)

**Table 2** Numbers of participants (% of total number in each workstation) suffering from symptoms of musculoskeletal ailments in different body parts during last 12 months

| Body parts | Experimental group | Control group |
|---|---|---|
| | Granulator workstation (n = 10) | Administrative and supervisory employees (n = 15) |
| Shoulder (both) | 5 (50 %) | 0 |
| Elbow (Both) | 2 (20 %) | 0 |
| Wrist (right) | 2 (20 %) | 0 |
| Wrist (both) | 5 (50 %) | 0 |
| Upper back | 0 | 1 (6.7 %) |
| Low back | 8 (80 %) | 2 (13.3 %) |
| Knees (one/both) | 5 (50 %) | 1 (6.7 %) |
| Hip (one/both) | 4(40 %) | 0 |
| Neck | 0 | 2 (13.3 %) |

Visual representation of the simulated environment for virtual evaluations is shown in Fig. 2 (considering the example of 50th p male manikin).

The OWAS, REBA scores and the L4-L5 spinal load analysis (using digital human modeling software) for selected working postures (Figs. 1 and 2) is shown in Table 3.

The L4–L5 compression values for all manikins (5th p, 50th p and 95th p) were within maximum permissible limits (Table 3) for all the selected working postures under evaluation. The L4–L5 joint shear values were within safe limits (Table 3). Postures ‘a’, ‘b’ (Figs. 1 and 2) contributed to high risk level on right side of the body while imposing medium risk on left body side as per REBA analysis. OWAS analysis recommended corrective action to be taken in near future. This was due to the presence of many body segments in uncomfortable angular range of motion and unacceptable body balance (Fig. 2). Working postures ‘a’ and ‘b’ (Figs. 1 and 2)

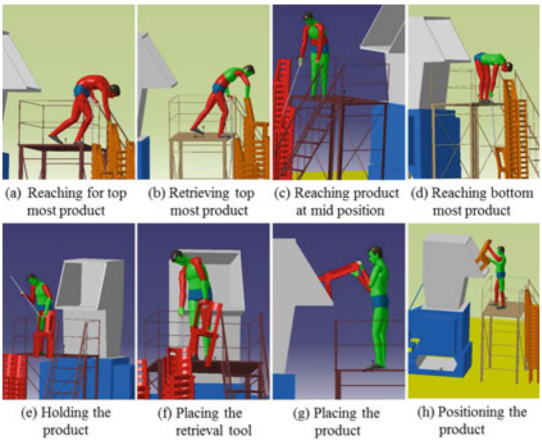


**Fig. 2** Virtual representation of working postures, 50th p male

**Table 3** OWAS, REBA and spinal load analysis of working postures

| Posture (see Fig. 1) | OWAS | REBA (Rt) | REBA (Lt) | L4–L5 Spine Limits Range (Newton) | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | | | Digital manikin | | | | | |
| | | | | 5th p | | 50th p | | 95th p | |
| | Action category | Score | Score | Compression limits | Joint Shear limits | Compression limits | Joint Shear limits | Compression limits | Joint Shear limits |
| a | 2 | 9 | 6 | 458 –1995 | 21–145 | 1328 –4023 | 43–168 | 1295–3172 | 21–160 |
| b | 2 | 8 | 6 | | | | | | |
| c | 2 | 4 | 6 | | | | | | |
| d | 2 | 8 | 5 | | | | | | |
| e | 2 | 9 | 9 | | | | | | |
| f | 2 | 9 | 8 | | | | | | |
| g | 1 | 2 | 4 | | | | | | |
| h | 2 | 3 | 6 | | | | | | |

*Rt* Right body side; *Lt* Left body side was recommended to be avoided at all costs and therefore not considered for further investigations in subsequent evaluations. Pushing and pulling actions are generally performed most easily between shoulder height and elbow height or a little below [17]. In present study, workers were found to lift the product well above shoulder level (posture 'h'; Figs. 1 and 2) in order to convey it into grinding slot after initially placing the product in the respective machine slot (as seen from working posture 'g'; Figs. 1 and 2). REBA analysis indicated low (change might be needed) and medium risk (investigate further and change soon) for left and right body side respectively, while OWAS analysis recommended corrective action to be taken in near future. Therefore, working method as found in posture 'g' (Fig. 1) is not recommended and should be changed. Operation chart was prepared (for both left and right hand) based on each work element in a work cycle in the existing granulator workstation as shown in Table 4.

**Table 4** Operation chart for work elements in a work cycle observed in existing granulator workstation

| Left hand | Symbol | Symbol | Right hand |
|---|---|---|---|
| Reach for railing | o | o | Reach for retrieval hand tool on platform railing |
| Grasp railing | O | O | Grasp retrieval hand tool |
| – | – | o | Lift retrieval hand tool |
| – | – | o | Change position and orientation of retrieval hand tool |
| – | – | o | Reach for chair with retrieval hand tool |
| Release grip on railing | O | O | Position retrieval hand tool on chair |
| Reach for chair | | o | Lift chair |
| Grasp chair | O | O | Release retrieval hand tool from chair |
| – | – | o | Change orientation and position retrieval<br>hand tool |
| – | – | o | Transport retrieval hand tool to railing |
| – | – | O | Release retrieval hand tool over railing |
| – | – | o | Reach for chair |
| – | – | O | Grasp chair |
| Carry chair towards grinding slot | o | o | Carry chair towards grinding slot |
| Position chair on grinding slot | o | o | Position chair on grinding slot |
| Lift chair for final push into grinding machine | o | o | Lift chair for final push into grinding machine |
| Push chair into grinding machine | o | o | Push chair into grinding machine |

*o* transportation (moving hand to grasp the article); *O* actions (grasping, positioning, using or releasing the article) (adopted from Barnes 1980) [15])

Length of the rod used by worker to lift defective product (chair) was 1180 mm while railing height from working platform base and railing diameter was 700 and 10 mm respectively. There was no toe board on the working platform.

## 4 Redesign and Evaluation of Granulator Workstation and Work-Accessories in Virtual Environment

Safety standards recommended in various literature sources were not included in the working platform design of the existing granulator workstation. For example, all staging, scaffoldings or platforms must be properly anchored, secured and placed firmly with railings at least 900 mm high [18]. Toe boards (100 mm high) should also necessarily be provided to prevent accidental falling of persons [18]. Tool boxes must be made available to decrease chances of fall of tools and also exposed sides of platforms be provided with toe boards to prevent falling of tools and loose materials if any [19]. Space requirement for a standing person should encompass 95th percentile arm span and the minimum dimension for whole body access through an aperture in a wall surface is to be 780 mm × 500 mm while wearing heavy clothing [20]. Maximal handle contact area which minimizes surface stress on the skin occurs on handles of 50–60 mm in diameter [20]. Anthropometry of user population should to serve as a guideline for geometric design of equipment and work places in order to ensure man machine compatibility [21]. If workforce is dominated by a particular gender then it is appropriate to design for the predominant gender [22]. Therefore, workstation and work methods were assessed and modified suitably for the male only. Various design recommendations (stated in earlier sections) pertaining to the immediate working area were suitably adopted in the CAD model of the granulator workstation (Fig. 3) for further evaluations on a virtual platform.

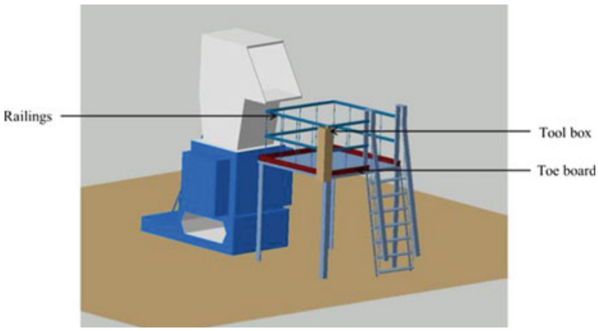


**Fig. 3** Modified model of granulator workstation and work-accessories

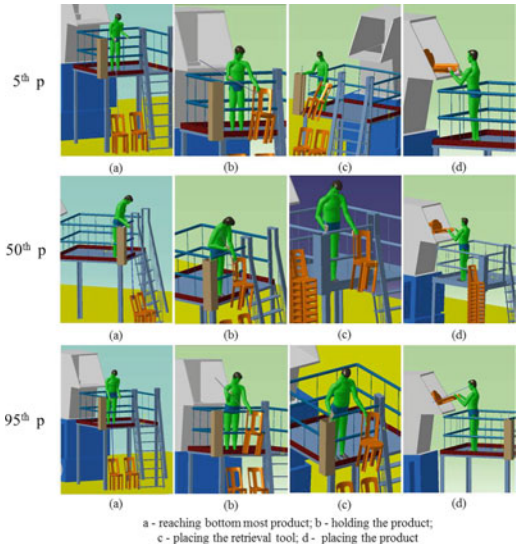


**Fig. 4** Evaluation of working postures in modified workstation

Observing improper work methods in the existing workstation, it was suggested that, the worker should place the product (chair) in an opposite (inverted) manner as shown in posture ‘d’ of Fig. 4 and lift it minimally for conveying it into the machine slot. Hence working postures ‘g’ and ‘h’ (Figs. 1 and 2) were combined into one single working posture represented by posture‘d’ (Fig. 4). This work method enabled to convey the product (chair) into the granulator machine at a position well below the shoulder height for all the manikins (5th p, 50th p and 95th p). Four postures (for evaluations with 5th p, 50th p and 95th manikins) were taken into consideration for further evaluations (Fig. 4).

Working postures ‘b’, ‘c’ (Fig. 4) corresponded to postures ‘e’, ‘f’ (Figs. 1 and 2). Posture ‘d’ (Fig. 4), in principle, characterized the combination of working postures ‘g’, ‘h’ (Figs. 1 and 2). Postures (as shown in Fig. 4) were rendered and evaluated after modifying the design of working platform. As it is obvious, if all manikins considered for the study (Indian adult male of 5th, 50th and 95th percentile body dimensions) are able to lift bottom most chair in the stack adopting comfortable working posture, then lifting chairs from middle position in stack will not pose a problem. Hence, working posture ‘c’ (Figs. 1 and 2) (lifting the product from mid position in the stack) was not taken into consideration for further evaluations. Main design variables found to be influencing the working postures is increase of railing height to 900 mm, provision of toe board to a height of 100 mm from the standing base of working platform and provision tool holder. Length of lifting rod should be approximately 2030 mm to facilitate comfortable working posture (without any postural risks and within safe biomechanical limits) for locating and retrieving bottom

**Table 5** OWAS, REBA and spinal load analysis of postures after design interventions

| Digital manikin (male) | Posture code | OWAS action category | REBA (Rt) | REBA (Lt) | L4–L5 spine limits (Newton) | |
|---|---|---|---|---|---|---|
| | | | | | Compression | Joint shear |
| 5th p (Fig. 4) | a | 1 | 2 | 2 | 862–1450 | 10–61 |
| | b | 1 | 3 | 4 | | |
| | c | 1 | 3 | 3 | | |
| | d | 1 | 1 | 1 | | |
| 50th p | a | 1 | 2 | 2 | 1167–2274 | 11–73 |
| | b | 1 | 3 | 3 | | |
| | c | 1 | 3 | 3 | | |
| | d | 1 | 1 | 1 | | |
| 95th p | a | 1 | 2 | 2 | 1091–1992 | 9–92 |
| | b | 1 | 1 | 1 | | |
| | c | 1 | 1 | 1 | | |
| | d | 1 | 1 | 1 | | |

*Rt* Right body side; *Lt* Left body side

most products from the stack for all manikins (5th p, 50th p and 95th p). Lifting rod of smaller length may be provided to facilitate easy and comfortable lifting of chairs from top positions of stack without compromising on working postural comfort. Postural analysis using REBA along with OWAS for postures ‘a’, ‘b’, ‘c’ and ‘d’ (Fig. 4) is shown in Table 5. All working postures (‘a’, ‘b’, ‘c’ and ‘d’; Fig. 4) were categorized as negligible and low risk for both sides of the body as per REBA analysis. OWAS analysis suggested that no further change was required. Such improvement of working postures was possible by keeping body joints at neutral position of their range of movement (indicated by green color coding on manikin’s body surface during assessments). Postural comfort is found to be the greatest in resting position or when the joints are in midpoint of the allowable range of movement whereas extreme postural discomfort is experienced at extreme position of joint rotation [23]. Working in comfortable posture depends on optimal positioning of each body joint. A good posture is the one which minimizes the biomechanical stresses on body [24] and should be kept within safe limits when the work involved material handling [25]. L4–L5 spine compression and joint shear data (obtained from digital human modeling software) were well within recommended limits for postures ‘a’, ‘b’, ‘c’ and ‘d’ (Fig. 3) as shown in Table 5.

Operation chart of the work elements anticipated after workstation design modifications showed reduction of work elements in a work cycle as shown in Table 6.

**Table 6** Operation chart for work elements in a work cycle anticipated in the proposed workstation

| Left hand | Symbol | Symbol | Right hand |
|---|---|---|---|
| Reach for railing | o | o | Reach for retrieval hand tool in tool box |
| Grasp railing | O | O | Grasp tool |
| – | – | o | Lift retrieval hand tool from tool box |
| – | – | o | Reach for chair with retrieval hand tool |
| – | – | o | Position retrieval hand tool on chair |
| – | – | o | Lift chair |
| Release grip on railing | O | – | – |
| Reach for chair | o | – | – |
| Grasp chair | O | – | – |
| – | – | O | Release retrieval hand tool from chair |
| – | – | o | Transport retrieval hand tool to tool box |
| – | – | o | Position retrieval hand tool on tool box |
| – | – | O | Release retrieval hand tool |
| – | – | o | Reach for chair |
| – | – | O | Grasp chair |
| Transport chair towards grinding slot | o | o | Transport chair towards grinding slot |
| Position chair on grinding slot | o | o | Position chair on grinding slot |
| Lift chair for final push into grinding machine | o | o | Lift chair for final push into grinding machine |
| Push chair into grinding machine | o | o | Push chair into grinding machine |

*o* transportation (moving hand to grasp the article); *O* actions (grasping, positioning, using or releasing the article) (adopted from Barnes 1980) [19])

## 5 Conclusion

Existing granulator equipment was installed and commissioned after purchasing it from the original equipment manufacturer. Other existing work accessories (working platform and retrieval hand tool) were custom designed and installed by workers themselves with the help of factory managements without considering basic ergonomics design principles. This scenario has led to prevalence of physical mismatch between worker's anthropometry and overall workstation design as well as with the work methods. Existence of musculoskeletal troubles significantly affecting the granulator workstation workers was identified. Non-conformance of workstation design and work methods to recommended guidelines (due to lack of proper awareness regarding laws of work, design guidelines proposed by national and international standardization organizations/researchers) led to incidence of awkward working postures. As overall workplace design and work methods were was found to be inadequate from ergonomics design perspective, investigations and subsequent modifications was very much needed in the granulator workstation. Research outcome towards modification of work method and redesigning of the granulator workstation considering demographic constraints enabled significant downgrading the risk perception of working postures. Workplace design is simplified with help of computer aided techniques using digital human models. Research methodology reported in the present research may easily be adopted by engineers/managers/supervisors in MSMEs of IDCs towards identifying physical ergonomics risk factors and developing validated context specific design solutions for humanizing work environment.

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# Ergonomical Study of Workplace Using the Technique of Path Process Chart

**Poonam Magu, Kumud Khanna and Premavathy Seetharaman**

**Abstract** The design of any workplace should be such that it enables the worker to perform the work with efficiency and with minimum of strain on his health and safety. The information for such a design can be generated only after an in-depth study has been conducted of the way the particular work is being performed by a worker at a given workplace. Once such an information is available, it can be used to design a more suitable workplace where the work can be performed with greater ease and higher productivity. The present study used the technique of Path Process Chart to study the work of meal preparation as was being performed by 50 homemakers in their kitchens. The Path Process Chart made it possible to study, both the work and the way the workplaces were being used by one or two workers, all at the same time.

**Keywords** Ergonomics · Path process chart · Domestic kitchens · Time and motion study · Workers · Workplace · Work centres · Flow of work · Meal preparation

## 1 Introduction

Ergonomics, deals with various aspects related to the work, worker and workplaces. Its ultimate aim is to enable one to design processes, workplaces, products, tools etc. in a way that the worker is able to perform the work efficiently [1]. The worker's health and safety should always be the main focus followed by increased productivity and good quality [2]. In order to design such suitable workplaces, it is imperative to understand the way work is performed by a worker in conventional

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workplaces and then to modify the workplace keeping in mind the flow of work and its requirements, [3–9].

Some studies have been conducted in India using different time and motion study techniques such as the process chart [10–12] flow chart and the string diagram [13, 14].

### 1.1 Aim

The specific objective of the study was to understand the way in which the different workplaces were being used in an urban Indian kitchen during the activity of meal preparation with the help of Path Process Chart so that essential information could be generated for designing a more worker friendly and efficient kitchen.

## 2 Method

The study was carried out in the kitchens of apartments built by Delhi Development Authority for middle income group families. The four regions i.e. North, South, East and West Delhi were covered. The study was conducted in three phases.

### 2.1 The Exploratory Phase

In this phase, 510 homemakers who were not gainfully employed outside the home were interviewed to gather data related to their personal and family characteristics such as their age, education level, years of marriage, type of family, family size etc. The information related to meal preparation such as the number and types of items cooked, the number of meals and timing of their preparation etc was also collected. The kitchens were also visited and specific information related to their size, shape of counter, changes made over the original design etc were also noted.

### 2.2 Development of Path Process Chart

During this phase, a new technique was developed which was later termed as the Path Process Chart. This technique records both the process of work as well as the use of workplaces or the path taken by the worker simultaneously [15].

The technique was developed at the Institute of Home Economics. It was later field tested in 10 domestic kitchens. Subsequently it was tested in the laboratory of the Department of Resource Management of the Institute of Home Economics where five menu items were made by the worker and the recordings were done both on the Pathway chart and the Path Process Chart. The analysis showed that the Path Process Chart gave the same information as the Pathway chart and also generated additional information regarding the way the work was performed.

A Path Process Chart consists of about 20 columns as can be seen in Fig. 1. The initial 13 columns are for the workplace address. The workplace address is given on the basis of the major equipment present at that workplace or in its close proximity. For e.g. in this particular study, Do was the door, S was the sink, R was the range, RF was refrigerator and EA stood for eating area. The workplace on the left of R was denoted by *R and on its right by R* and so on and so forth. The same was done with other workplaces as well, such as the sink. The workplaces, where there were no major equipments or no other distinct features, were named as 1 and then 2 and so on. The presence of any other workplace was denoted by AO. If it is a large work area and there are more numbers of workplaces, then the columns can be increased accordingly.

The next four columns are for noting the process i.e. operation (O), transport (T), delay (D) or storage (S) performed at those workplaces. The column for noting time comes next followed by another column for listing the equipments used. The final column is the remark column.

It is a simple paper and pen technique. After noting the time when the activity begins, the researcher has to draw a line from one workplace to the other as per the movements made by the worker. The symbols in the process columns are circled or marked. The time can be noted after every one minute or more or less depending upon the requirements of the study. Similarly, the equipments and major ingredients used can also be noted in the equipment column. In the remark column, the steps are written.

In case, one of the objectives of the study is to calculate the total distance covered by the worker, then the plan of the work area can be prepared beforehand as per a scale. Later, the distances between the different workplaces can be measured on the plan and multiplied with the number of trips made between the workplaces. The sum of these will give the total distance covered.

If a second worker joins in to perform the work, then her movements can also be traced on the same chart either by using a different coloured pen or a different type of line.

Let us consider the activity of preparing tea the Indian way. A worker enters through the door of the kitchen and goes to the workplace on the right of the sink (S*). A transport is noted in the process column and a line is drawn from the door (Do) to the workplace to the right of sink (S*).

She picks up a saucepan. Storage is marked in process column while the movement line remains at S*. She fills the pan with water which is an operation. The O in the process column is marked. She then moves to the range (R). A transport is marked in the process column and the movement line goes to R. Subsequently, the entire process is marked on the chart along with the movements of the worker. Many times, a worker does not have to physically move from one workplace to the other as the other workplace might be close by. For e.g. the

| Do | *S | S | S* | *R | R | R* | RF | EA | 1 | 2 | 3 | AO | O | T | D | S | Time | Eqpmt | Remarks |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Do | *S | S | S* | *R | R | R* | RF | EA | 1 | 2 | 3 | AO | O | T ✓ | D | S | 6.01 | | Enters, goes to S* |
| Do | *S | S | S* | *R | R | R* | RF | EA | 1 | 2 | 3 | AO | O | T | D | S ✓ | | Sauce pan | Gets Pan |
| Do | *S | S | S* | *R | R | R* | RF | EA | 1 | 2 | 3 | AO | O | T ✓ | D | S | | | Goes to Sink |
| Do | *S | S | S* | *R | R | R* | RF | EA | 1 | 2 | 3 | AO | O ✓ | T | D | S | | | Fills water |
| Do | *S | S | S* | *R | R | R* | RF | EA | 1 | 2 | 3 | AO | O | T ✓ | D | S | | Range | Goes to range R |
| Do | *S | S | S* | *R | R | R* | RF | EA | 1 | 2 | 3 | AO | O ✓ | T | D | S | 6.02 | | Puts pan on range |
| Do | *S | S | S* | *R | R | R* | RF | EA | 1 | 2 | 3 | AO | O | T ✓ | D | S | | | Goes to R* |
| Do | *S | S | S* | *R | R | R* | RF | EA | 1 | 2 | 3 | AO | O | T | D | S ✓ | | Tea Lvs | Gets Tea Leaves |
| Do | *S | S | S* | *R | R | R* | RF | EA | 1 | 2 | 3 | AO | O | T ✓ | D | S | | | Goes to range R |
| Do | *S | S | S* | *R | R | R* | RF | EA | 1 | 2 | 3 | AO | O ✓ | T | D | S | | | Adds tea |
| Do | *S | S | S* | *R | R | R* | RF | EA | 1 | 2 | 3 | AO | O | T ✓ | D | S | 6.04 | | Goes to R* |
| Do | *S | S | S* | *R | R | R* | RF | EA | 1 | 2 | 3 | AO | O | T | D | S ✓ | | Sugar | Gets sugar |
| Do | *S | S | S* | *R | R | R* | RF | EA | 1 | 2 | 3 | AO | O | T ✓ | D | S | | | Goes to range R |
| Do | *S | S | S* | *R | R | R* | RF | EA | 1 | 2 | 3 | AO | O ✓ | T | D | S | | | Adds sugar |
| Do | *S | S | S* | *R | R | R* | RF | EA | 1 | 2 | 3 | AO | O | T | D | S ✓ | | Milk | Reaches for milk |
| Do | *S | S | S* | *R | R | R* | RF | EA | 1 | 2 | 3 | AO | O ✓ | T | D | S | 6.05 | | Adds milk |
| Do | *S | S | S* | *R | R | R* | RF | EA | 1 | 2 | 3 | AO | O | T | D ✓ | S | | | Waits to boil |
| Do | *S | S | S* | *R | R | R* | RF | EA | 1 | 2 | 3 | AO | O | T ✓ | D | S | 6.06 | | Leaves kitchen |
| TOTAL | | | | | | | | | | | | | 5 | 8 | 1 | 4 | | | |

**Fig. 1** Path process chart for the activity of tea making

workplace towards the left of the range (*R) might be so close to the range that the milk jug placed there can be picked up by simply reaching out. In such a case, a broken arrow is made extending from R to *R to signify a reach.

Once the activity comes to an end the total number of operations and storages performed, delays encountered and transports made can be counted. The time taken for the activity to get completed can be noted, Subsequently the data collected can be analysed using the distance chart, trip—frequency chart, operation chart, storage chart [15].

### 2.3 Use of Path Process Chart for Studying the Activity of Meal Preparation

The Path Process Chart was used to study the activity of meal preparation in the kitchens of 50 apartments built by the Delhi Development Authority for middle income group families in the four districts of Delhi. The meals were prepared by homemakers selected from the sample of 510 homemakers interviewed in the first phase of the study. The criteria for selection was that they should be preparing all the items, to be served at one meal, together.

## 3 Results and Discussions

### 3.1 Personal Characteristics

The analysis of the data revealed that the mean age of the 50 homemakers was 44.46 years. In terms of their educational qualifications, 52 % were graduates and 34 % post—graduates. Most of them i.e. 76 % had been married for more than 10 years.

### 3.2 Physical Characteristics of the Kitchen

The data related to the physical characteristics of the kitchens was also collected. It was found that the size of the kitchen ranged from 4.45 to 6 sq.mts. The majority of the kitchens i.e. 62 % had L shaped counter, 26 % had U shape, 8 % had counter against one wall and 4 % had counters against two walls.

### 3.3 Work Places Used During Meal Preparation

The Path Process Chart generated important information regarding the flow of work and the way the different workplaces were used during the activity of meal preparation.

**Workplaces present in the kitchen**. During meal preparation various workplaces were used. The major ones were—the range (R), sink (S), workplaces to the left / right of range (*R/R*), workplaces to the left/right of sink (*S/S*), workplaces at the junction of the workplace towards the right of range and the workplace towards the left of the sink (R**S), utensil stand (UT), cupboard (C), refrigerator (Ref), workplace on the third arm of the U shape counter where no major equipment has been placed (1). In addition, there were other minor workplaces as well.

**Workplaces outside the kitchen**. There were some workplaces outside the kitchen which were also being used for the purpose of operations or storage. The refrigerator was outside the kitchen in 75 % of the households. The eating area was also being used by 50 to 75 % for chopping or cutting vegetables. 25 to 50 % were using the cupboard in the drawing room or bedroom for storing items. About 25 % were using their balcony or backyard for growing herbs which they would cut fresh while making a meal.

## 3.4 Operations Performed at Different Workplaces

Altogether, 32 operations of meal preparation were observed. These included 19 pre-preparation operations such as peeling and chopping vegetables, kneading, rolling '*chappattis*', mashing, grinding etc., 8 cooking and 5 washing operations. The actual cooking of items was done exclusively at the range just as washing of vegetables, pulses, hands, kitchen duster was done at the sink but the pre-preparation operations were performed at different workplaces in the kitchen.

There were five workplaces i.e. the range (R), the left of the range (*R), the right of the range (R*), Sink (S) and in the kitchen with U shape counter—the workplace on the third arm of U i.e. (1) where more than 10 operations were performed and these can be termed as the major workplaces. Out of these, the range and the workplaces to the right and left of it were the most important ones as far as cooking and pre-preparation are concerned.

## 3.5 Workplaces Used for Storage

The analysis of the data revealed that although there were some specific workplaces for performing operations, the entire kitchen was used for the storage of some item or the other. More specifically, the range and workplaces to its left or right, sink and workplaces adjacent to it were the most important storage areas in the kitchen.

### 3.6 Frequency of Use of the Different Workplaces

The importance of a workplace can be judged by the frequency of its use. The present study revealed that the range was the most frequently used workplace followed by the sink and then the workplace to the left of the range (*R). The workplace to the left of range (*R) was used more often than that towards the right since all the respondents were right handed. Thus, it was more convenient to work at a workplace to the left of the range so that simultaneously operations could be performed at the range with the right hand.

### 3.7 Relationship Between Different Workplaces

The relationship between different workplaces can be seen from the number of trips made between different workplaces. This relationship can act as a guide in the placement of workplaces. The workplaces between which trips are made more often should be placed close together so as to reduce the distance to be travelled by the homemaker during meal preparation. Nimkar and Tarnikar [16], also reported saving in distance and time through reorganisation of kitchen centres.

The present study revealed that out of the total of 22 workplaces, maximum number of trips were made from 17 workplaces to the range. This once again, highlights the importance of range in an Indian kitchen. The association between the range and the sink was also found to be the strongest and two should therefore be placed close to each other. The refrigerator was visited most often from the range and it was to the range that most of the trips were made from the refrigerator. The eating area was visited most often from the range and then from the refrigerator. This would be the case since in Indian cooking, the '*chappatis*' are served hot from the range to the eating area and it involves a number of trips.

### 3.8 Workplaces Between Which Work Was Performed by Reaching Out

The Path Process Chart makes it possible to study work which is performed by reaching out. Sometimes the workplaces are present close to each other so that the worker does not have to physically move to the other.

The study revealed that the work was performed by reaching out from the workplace to the right or left of the range and workplace 1 to range and vice versa. An analysis of the operations performed at these workplaces highlighted the fact that most of these operations were those that occurred in a sequence. Thus, rolling out of 'chappatis' was done at the workplaces close to the range but the puffing of chapatis was done by reaching out to the range (R). Work by reaching out was also performed between the sink and the workplaces to its right or left.

### *3.9 Important Centres in the Kitchen*

As is evident from the above discussion, particular kind of work was being carried out at *range, range and range* and then again at the *sink, sink and sink* for which the work surface and most of the ingredients and equipments needed to perform the work and storage space for these were present at these workplaces. These findings point towards the existence of centres in the kitchen. On the whole, range centre and sink centre were the two most important centres present in the urban kitchen belonging to middle income group families. Out of these, range centre was the most important followed by the sink centre. Kotecha [17], also conducted a time and motion study of meal preparation in a home management house of M.S. University, Baroda and found, after analysing the pattern of trips made by the subjects, the range centre to be the most used centre in the kitchen. This is unlike the kitchens of the western countries. In the study conducted by Steidl [18] at the Cornell University Agricultural Experiment Station, the sink centre was found to be the most used centre.

### *3.10 Time Used*

The study revealed that on an average 72 % homemakers spent less than one hour and the remaining 28 % spent more than one hour on meal preparation. As the study was conducted under natural conditions, in the kitchens of the homemakers. it was found that there were many interruptions that caused the unnecessary delay in the completion of the task. The delay was inherent in the case of 16 respondents who had to wait for the food item to get cooked before starting another activity. For e.g. these respondents had to wait for the 'masala' of the curry to get done. In case of 5 respondents, the delay was intentional as they wanted to intentionally stop the activity so that they could talk to their family members. In the case of another 15 respondents, the major cause of the unexpected delay was the phone and the door bell.

The causes of delay highlights the need for better planning and work organisation by the worker. The inherent delay can be avoided if the homemaker plans her work so that the active phase of one activity overlaps the inactive phase of another. The intentional delay is a matter of personal choice made by the homemaker whereby she could, in order to break the monotony of work, interact with others. Although, the unexpected delays cannot always be avoided but delegating such tasks as answering the doorbell or the phone call to another family member can also reduce the number of such delays.

## 3.11 Distance Travelled

The activity of meal preparation is not only time consuming but also involves heavy expenditure of energy. About 54 % of homemakers travelled between 50 and 100 mts., 36 % between 150 and 250 mts. and 10 % above 250 mts during the preparation of one meal that was observed. Similar findings were reported by Gill [19] in her study on disposition of work centres.

## 3.12 Equipment Used

The pressure cooker was used by 86 % of the homemakers In the remaining 14 % of the cases only basic cooking utensils were used. Gulati [20] also reported that pressure cooker is used by most of the homemakers The use of an electric mixer not only reduces time but also saves the energy of the homemakers. In the present study, however, only 14 % were using it during meal preparation.

## 3.13 L Shape Kitchen Counter Versus U Shape Kitchen Counter

There were 62 % of kitchens which had U shape arrangement of counter, 26 % with L shape arrangement, 8 % with counter against one wall and only 4 % with counters on 2 walls. The major difference that was seen was in the number of workplaces used for performing operations or for the purpose of storage Thus, in 84.6 % kitchens which had U shape arrangement, five or more workplaces were used for performing operations related to meal preparation as compared to 38.7 % of kitchens with L type of arrangement and 25 % with one wall arrangement.

Similarly, in almost 54 % of the kitchens with the U type arrangement of counter, 8 or more workplaces were used for the purpose of storage as compared to 32.4 % kitchens with L type arrangement of counter, 50 % each with one wall. Arrangement and two wall arrangement of counter.

Another observation was that as compared to average time of 53 min spent in meal preparation in kitchen with U shape arrangement of counter, only 48 min were spent in the kitchen with L shape arrangement. Similarly, the distance travelled was also more in the U shape as compared to L shape—180 m in the U shape as compared to 134 m in the L shape.

A Multiple Logistic Regression Test was applied to study the difference between the two different arrangements of counters in terms of the average time taken, average distance travelled, average number of destination points, average number of destination points where operations were performed, average number of destination points where pre-preparation operations were performed and average number of destination points where storage was performed. The model revealed that the two kitchens differed only in terms of the number of destination points where operations were performed—the U shape kitchens had more number of destination points than L shape.

Thus, as the workplace space increases and more space is available to perform the work, the worker tends to ‘scatter’ the work. This results in the use of more number of workplaces and subsequent increase in distance and time of the worker.

In a way then, it can be said that the L shape arrangement of counters is better than U shape. This was also reported by Lognayaki and Saramma [21], in their study of kitchen work centres. They arranged the work centres in different arrangements and studied the effectiveness of each. The evaluation done with 25 homemakers revealed that the homemakers were satisfied with the L shape arrangement of the work units as they were more compact, convenient and easy to work with.

However, in most Western countries, it is the U shape arrangement which is found to be more time and energy saving. In the studies conducted at the Purdue Motion and Time Study Laboratory [22], the three standard arrangements of kitchens i.e. two wall kitchen, the L shape and U shape were studied. Within the conditions of the study, the U shape kitchen proved the most effective. It took 35 min in the U shape kitchen as compared to 58 min in two wall kitchen to prepare the same meal.

In the present study, although there were more number of destination points which led to more time and distance travelled by the worker, keeping in mind the increasing storage needs of the family and the growing market economy which is producing more and more different types of labour saving devices, it can be suggested that the kitchen should have a U shape arrangement. The worker, however, must organise her workplace well and must develop the centre concept in order to reduce her own physical cost of work.

## 4 Conclusion

To conclude, it can be said that the technique of Path Process Chart can be used for conducting an in-depth study of a work place. In the present study, it was found that the activity of meal preparations involves various operations which are performed at a number of workplaces. The storage of items required for meal preparation are also many and almost the entire kitchen is used towards that end.

The range centre has emerged as the most important work centre comprising off the range and workplaces close to it. The sink centre is next in importance.

The worker spends less time and also travels less in a L shape kitchen as compared to U shape. However, because of increasing need for space both for carrying out varied operations and for the purpose of storage, it is better to opt for a U shape. The worker must be trained to develop the centre concept and to work systematically in order to save her resources of time and energy.

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# Cooperation University and Industry, a Challenge or a Reality: An Example in an Aircraft Maintenance Company

**Francisco Rebelo, Paulo Noriega, Teresa Cotrim and Rui B. Melo**

**Abstract** This paper discusses a strategy to integrate ergonomics in aircraft maintenance industry. The program is a systemic and integrated project that involves: training for the workers; ergonomics analysis and intervention and research. The objective is to develop basic competences in ergonomics among team leaders, improve the working conditions and increase the production efficiency and effectiveness. In this particular industry, poor working conditions can influence the workers performance and lead to Human errors that can be responsible for aircraft problems later. After a two-year intervention program, the main results showed: a high level of motivation among the workers; the involvement of the workers in the development of solutions to improve the working conditions; and the involvement of the company and the university in long-term research projects. A discussion about the opportunities and difficulties in the collaboration between University and industries is also presented.

**Keywords** Aircraft maintenance · Cooperation with university · Participatory design

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## 1 Introduction

For the International Aviation Transportation Association (IATA), the Human issues are the primary concern in aviation safety, while mechanical issues are a secondary concern [1]. Despite this concern, maintenance errors are responsible for 12 % of air aircraft crashes [2]. A study from Hackworth, Holcomb, Banks, Schroede, and Johnson [3], report that over 15 % of accidents are related with problems with aircraft maintenance. Another study developed by Phillips [4] concluded that 18 % of all accidents are maintenance related.

A report made by the Civil Aviation Authority of UK [5] described a list of maintenance errors that comprise: incorrect installation, wrong wiring, inadequate lubrication and leaving tools and objects in the airplane. The main reasons of such errors are related with organizational issues that initiated a chain of deviation, errors and breakdowns. Mica Endsleya and Michelle Robertsonb [6], introduced another important issue, they showed that insufficient attention has been responsible for human error in aircraft maintenance.

To be efficient aircraft maintenance tasks require work coordination, cooperation and communication between inspectors, maintenance workers, supervisors and various other groups related with engineering planning, components store and safety and health staff. In a routinely procedure, the inspector looks for problems in the aircraft and report them to be repaired. The maintenance workers fix the problems and work with the inspector to verify if the work meets predefined standards imposed by the aircraft manufactory.

Ergonomics can play an important role in this context but, unfortunately, in general the expectation of the society is to consider ergonomics only related with musculoskeletal problems derived from work. We can understand this perspective, which is derived from the more visible side of the organizations problems. The musculoskeletal disorders related with work are the major cause of work absence and can reduce the worker performance, affecting the work quality [7]. Particularly, Irwin and Streilein [8] identified in a large airplane maintenance facility an increasing trend in the population of aircraft painters of permanent physical disabilities.

Within this framework, this article aims to present and discuss the link between an aircraft industry and a Higher Education Institution in Portugal that teaches and investigates Ergonomics. According to Wright [9], working with Universities poses considerable challenges. The academic need to publish is at times conflicting with industries need to protect the knowledge and technologies they use. Another problem is related with different objectives, while the academic work focuses on big and long period challenges, moving slow, day-to-day project solving drives the industry. As a result, industry believes that Universities are too slow to be good partners. Another problem is related with the manager's lack of knowledge about the services that Universities can provide for them.

## 2 The Proposed Intervention Model

This project began based on an aircraft maintenance company demand to solve problems related with workers musculoskeletal problems. Our first objective was to demonstrate to the company managers, that ergonomics is not only related with physical problems (in this case with postures). To accomplish good results we needed to have a systemic perspective of the work, including the integration of the physical, cognitive and organizational levels. Moreover, ergonomics aims not only at identifying the problems, but to find the best solution to solve them. All the workers, team leaders and directors, needed to be involved with the ergonomics team, to find the adequate solution, having in mind the company constraints.

Figure 1 shows the model accepted by the company. The model is composed by three main areas: training; analysis and ergonomic intervention and investigation.

### 2.1 Training Program

The training program was implemented in a learning-by-doing perspective, where the workers bring to the classroom their work problems, to be analyzed and discussed. In this context, the ergonomics knowledge to support the analysis and the proposed solutions are taught. The problems arise from the workplace issues that can affect, in a systemic perspective, the health and safety of the workers, the efficiency and effectiveness of the productive system and the product quality. The classes are ministered inside the company, to minimize the workers displacements and to have the possibility to analyze and discuss the problems in the work field,

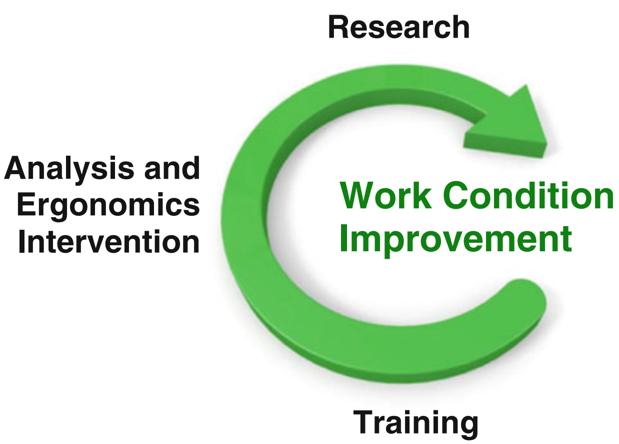


**Fig. 1** Integrated model for the ergonomics intervention between university and the industry

next to the workers. After each session, the workers can practice the methods and tools in the work field, allowing the possibility to have a real and immediate feedback on their performance.

This pedagogical strategy motivates the workers to be more attentive, putting interesting questions in the classroom. We cannot find this motivation in a normal University classroom, where the students normally don't feel that the ergonomics knowledge is integrated in their lives and don't have the opportunity to implement a solution and analyze the results in a real workplace situation, as most of them still have no job.

For this particular aircraft maintenance industry, based on the main identified problems, the training program concerned:

- Musculoskeletal problems associated with load manipulation tasks and poor postures in confined spaces;
- Human error in the task failure identification, related with the aircraft structures and engines;
- Visual fatigue in the task failure identification, related with the aircraft structures and engine;
- Inadequate tools, particularly to work with in confined spaces;
- Inadequate equipment's to work bellow the aircraft;
- Psychosocial problems related with teamwork;
- Workload in a population with an average age of 45 years.

The model for this training program was developed in sessions of four hours each week. During the week the workers can send doubts and questions by email.

We created a multidisciplinary team with four Professors, all ergonomists, with a research background in safety engineering, cognitive psychology, health and design, to conduct this training.

The main objective of this intervention was to create a basic ergonomic knowledge inside to the company, empowering the workers in the identification of the least complex problems and development of solutions that could be easily implemented. For the complex problems involving high competences in ergonomics and large investments for the company, the workers ask for help and collaborate with the University in a participatory design perspective, to find the best solution.

## 2.2 Analysis and Ergonomic Intervention

The analysis and ergonomic intervention occur simultaneously with the training sessions and involve the traditional ergonomic analysis of the work situation (task analysis and work activity analysis) and the use of bi-dimensional computer mannequins to propose solutions for the workplaces. In some special situations, the group from the Ergonomics Laboratory used complex models, like three-dimensional computer mannequins and the HARSim (Humanoid Articulation Reaction Simulation) model, that allows to calculate the reaction forces and stresses, at all levels of the vertebral column [10].

In this phase, the workers have a good perception of the restrictions, particularly financial ones, and the technical requirements of the aircraft manufactures.

Some proposals arise from the Kaizen groups that needed functional requirements of the worker interaction with the new work situation. At beginning, they think that the University proposals are very complicated and not compatible with the resources of the group (in terms of time and finance). In this particular case, it was very important to have a balance between the need to have a quick solution and a good scientific backgrounds supporting the proposed solutions. For these circumstances we have created special groups, involving students from the Ergonomics under-graduation and Master degree courses in Ergonomics.

The main objective of those interventions was to identify and study the problems and propose solutions, normally implemented by the worker with the supervision of the University team, that didn't involve large investments for the company.

## *2.3 Research*

The research arised from the complex challenges of the aircraft company, which required a complex analysis, involving specialized researchers and long periods of work. Laboratory researchers, Master and PhD students were involved in the study of the problems and proposed solutions to improve the working conditions. In those situations an immediate result was not expected, but rather a solid solution for a complex problem.

Some examples of problems that we have studied are related with the ageing of the workers and future solutions for the possible decrease of the younger workforce. In this particular company, where the mean age of the workers was 45 years, this will be a huge problem in the near future. Mainly for the tasks that require a high degree of expertise from the workers, like diagnosis of failures in the structure of the aircraft and in painting tasks. Identifying those situations to prepare the modification of the working conditions is a huge task, which involves investments that need to be prepared before the main problems arise.

The other type of research was related with the development of solutions that involves investment to be implemented. In those situations a full ergonomic study of the work situation is required to justify the need and a detailed solution supported by a cost-benefit study.

In synthesis, the main objective of this intervention is to develop studies and propose solutions for complex problems, which may involve large investments for the company.

## 3 Organizational Structure of the Intervention Model

Table 1 shows the organizational structure of the program, which regulates the cooperation work between the Company and University staff. We created two director committees to coordinate the project.

The committee of the company was composed by the CEO, and both the Human Resources and the Health and Safety Directors, having the following objectives:

- Define the work program with the team of the ergonomic laboratory of the University.
- Allocate the necessary resources (financial and human) to the program.
- Discuss and orientate the implementation of the recommendations and solutions.

This group meets once a year with the University committee group to analyze the achieved results and propose corrections that can improve the program.

The committee from the University is composed by the 4 Professors, researchers in the Ergonomics Laboratory and has the following objectives:

- Propose a pedagogical strategy for training the working groups of the company, according to the identified problems and needs in ergonomics.
- Deliver training sessions to the company working groups.
- Analyze the solutions proposed by company groups and give orientations to reach good results.
- Propose recommendations and solutions and discuss them with the company working groups.
- Develop studies with Ergonomics students to analyse and propose solutions for complex problems.

The coordination committee is composed by professionals from both institutions and has the following objectives:

- Develop synergies between the Company and the University groups.
- Accompany and support the activities of the workgroups.

The working groups from the Company are composed by team leaders, safety and health technicians and workers and has the following main objectives:

- Participate in the training sessions developed by the team of the ergonomics laboratory.

**Table 1** Organizational structure of the program

| Company | ErgoLab University |
|---|---|
| Company director committee | University director committee |
| *Coordination committee* | |
| Company work groups | University work groups |

- Develop strategies to evaluate the work situations, depending on the problems.
- Propose recommendations and solutions along with ergonomics team of the Ergonomics Laboratory
- Follow-up the implementation of the proposed solutions.

## 4 Main Results

In this paper we present the main results of this program, after two years of intervention. The results will be presented for each area of intervention: training, ergonomics analysis, and intervention and research.

### *4.1 Training*

At beginning, the group encompassed thirty-two participants, coming from the main areas of the company. The first main objective was to show that ergonomics is more than working postures. The basic knowledge on how to develop a task analysis and work activity analysis was the first content. Next, basic concepts associated with cognition and anthropometry were taught. After each session, the students had the opportunity to practice in the field, mainly regarding task analysis and work activity analysis.

The sessions took place in a room with all participants, on the first moment, and, in a second moment, in the field with small groups in order to not disturb the work of other workers.

The level of motivation was high; workers were very attentive in sessions and tried to relate the contents with problems connected to their working conditions. To develop the tasks proposed by the trainers, the workers remained in the company after the normal working time period.

In the second year, the number of participants decreased mainly due to the fact that some of them left the company. In other situations the decrease of participants was related with difficulties in attending the training due to a high workload.

### *4.2 Ergonomic Analysis*

After six months, the participants understood the broad sense of ergonomics and began to study problems related with: solutions for poor postures in the workplace; development of new work clothing to avoid skin high-pressure contacts; mobile platforms to work on aircraft structures; solutions to avoid noise problems in the work space; workbenches for inspection tasks of aircraft parts; the removal, storage and cleaning aircraft slave pallets.

For the less complicated problems, where it was possible to find a solution without a detailed study and the implementation was easy, the workers implemented it with the support of the ergonomics team from the Ergonomics Laboratory.

One of most important results of this intervention was the creation/increase of worker awareness about their work conditions and the possibility to improve the work situation with the help of ergonomics.

## *4.3 Research*

In the situations where a detailed ergonomic study was needed and the use of models, like three-dimensional digital humans and computer simulations, was required the staff of the Ergonomics Laboratory was involved. Those projects didn't have a temporal limitation that involved an immediate solution, giving the possibility to have a deep investigation.

An example of a project was the development of a new postural support to work under an aircraft. This equipment is to be used in repairing tasks under the aircraft, which requires the elevation of the upper limbs for long periods of time. The proposed solution will allow the accommodation of 90 % of anthropometric variation for two height work planes. The worker will develop their work tasks in a lying posture and will have an upper limbs support to avoid fatigue. The support will integrate a light source to provide better illumination of the work surface, avoiding visual fatigue, and some places to store the work tools.

This project and others allowed integrating master degree students, which participated in the projects development and developed competences for their professional future.

Another example was the assessment of the psychosocial factors among the workers of the maintenance sector. The Portuguese version of COPSOQ II [11] was used for characterizing the psychosocial factors [12]. The sample included 539 workers. 71.4 % of the workers perceived high cognitive demands. Positive factors were also perceived, such as good possibilities for development, high sense of community, high sense of auto-efficacy and good meaning of work. Age was correlated with the influence at work ($r = -0.17$; $p \leq 0.001$) and the commitment with the workplace ($r = -0.18$; $p \leq 0.001$), meaning that as workers age their sense of influence at work and of commitment with the workplace are stronger. These results pointed to favorable psychosocial factors present in these workplaces. In the same way, the health outcomes were positive with high percentages of workers perceiving the scales "sleep troubles", "stress", "depressive symptoms" and "general health" as favorable factors, regardless of the negative correlation between general health and age. One of the major psychosocial hazards experienced by the aircraft maintenance workers seemed to be the cognitive demands based on high attentional task demands. These results were understandable looking at the severe quality standards required in this industry and at the type of tasks performed comprising several visual and manual inspection operations. Through better division of tasks and inter-professional team building, this organizational demanding factor could be improved.

## 5 Discussion and Conclusions

The relationship between Universities and industry is tenuous and in most cases, we do not observe a good synchronization. It is clear the need that business has to get closer to the academic world and vice versa, but how can we do it?

Nowadays, companies do not believe that the University can help them [13]. Universities claim their role in providing theoretical knowledge, but also need to have a more applied vision, which is essential for companies. Particularly in the ergonomics field, the Ergonomics Laboratories need to adapt their priorities, giving attention to the applied knowledge closer to the company needs and not only studying theoretical issues.

In this project we developed a systemic and integrated program that involves: training, ergonomics analysis and intervention, and research, for an aircraft maintenance company.

We adopted a learning-by-doing strategy that motivated the workers to bring their working conditions problems to sessions and discuss them. The workers invested their time after the normal working hours to study and to develop solution proposals for their problems.

The workers in collaboration with the team of the Ergonomics Laboratory, developed ergonomics analysis to understand the work situation and proposed a diversity of solutions, mainly related with the objective to reduce physical and cognitive fatigue. During the interventions we found that some workers changed the way they look their work conditions. Now they are more able to identify the basic work condition problems and try to solve them and to ask for help in more complicated situations.

In the research domain, we developed studies that didn’t involve immediate solutions, more challenging for the University, but that will give good results in the near future. Particularly, the development of new equipment’s and a deeper understand of this workers’ population. The involvement of students from the Master degree course in Ergonomics was a good opportunity for them to learn in a real work context.

Now, after two years and some implemented solutions, it is rewarding and promising to have a group of workers with some competencies in ergonomics that will certainly contribute for their peers well-being and safety as well as for the efficiency and effectiveness of the productive system.

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# Postural Education: Correlation Between Postural Habits and Musculoskeletal Pain in School Age Children

**Gustavo Desouzart, Ernesto Filgueiras, Rui Matos and Ricardo Dagge**

**Abstract** The best way to avoid poor postural habits, is to teach children good postural behaviors for performing their everyday life activities (Verderi in Programa de educação postural, 2011 [1]). Despite the existence of specific programs, intended for children's self-body consciousness improvement, Physical Education curricula lack this type of exercises (Braccialli and Vilarta in Revista paulista de Educação Física 14: 159–171, 2000 [2]; Costa and Freire in Estudo dos exercícios físicos voltados para correções das alterações posturais, 2004 [3]; Ramos and Rodrigues in EFDeportes.com, 2013 [4]). Attended by 220 students, with ages between 10 and 15 years old, this study applied a technique (Corlett and Bishop in Ergonomics 19:175–182, 1976 [5]) for assessing postural discomfort, and an informal questionnaire (Carmo et al. in Metodologia da Investigação – Guia da Auto-aprendizagem, 1998 [6]; Rebolho in da educação postural nas mudanças de hábitos em escolares da 1ª a 4ª séries do ensino fundamental, 2005 [7]), to fully understand pain and postural discomfort felt by Portuguese school age children. Results showed: a significant direct correlation between the time, and the perceived intensity of pain felt, for chronicle and acute pain; regarding postural habits, 88.5 % of subjects presented some kind of inadequate postures, perceiving significantly higher pain. Major findings, allow us to raise the awareness for postural education

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programs introduction in Physical Education curricula, since they could influence children's physical health.

**Keywords** Musculoskeletal pain · Changes in postural habits · Postural education

## 1 Introduction

School age children's physical structure is in constant development. Besides changes felt in height and body weight, mostly because of individual experiences, children's posture also shifts. Children's bad postural behaviors is considered to be one of the main risk factors contributing to musculoskeletal disorders felt in adulthood, this is why Braccialli and Vilarta [2] claim the necessity of establishing early preventive measures.

First middle school years are crucial when it comes to the arising of musculoskeletal disorders in growth stage children, primarily due to bad postural habits adopted while carrying their school supplies to and from school. Those same bad postural behaviors, that Dagge and Filgueiras [8] concluded that may increase intervertebral pressure by almost 30 % for the same weight conditions.

According to Verderi [1], it is not uncommon for children to develop their own daily-life activities without receiving proper recommendations on how to avoid bad postural behaviors, by their Physical Education teachers.

In order to avoid musculoskeletal disorders, European Community prioritize preventive measures development among adults and children. This measures, based upon user's daily-life risks, are focused on aspects where Burton et al. [9] highlight lifestyle (which may include nutrition, work, physical activity and obesity), physical related (like mobility, flexibility and muscle strength), school environment related (which include backpack transportation and school furniture) and finally psychological related that according to them, after modified may reduce the occurrence of musculoskeletal problems among the general population.

In order to establish efficient health care criteria for growth stage children, studying the relation between children and adolescent's postural shifts and subsequent musculoskeletal disorders (whether they are acute, subacute or chronic),[1] is extremely relevant.

Literature defines posture through somatic and biomechanical aspects. According to Howe and Oldham [12], body posture only includes spine area, but they point out that all body parts play a key role in its alignment. Magee [13] considers posture as a compound of all human-body articulation placement, for her,

[1]Pain could be classified according to it's installation periodicity and maintenance. Under a 4 week period, pain could be classified as acute; from 4 to 12 week period, is considered to be a subacute pain; and for more than 12 weeks, the pain could be classified as chronic [10, 11].

the ideal posture is the one in which there is a minimum amount of stress applied to each of these structures.

Studies have been made that show spinal deviations due to bad postural behaviors adopted by children [14, 15]. Some of these may even be context related, as Dagge and Filgueiras [16] state.

According to Verderi [1] the best way to avoid postural changes is to adopt good postural behaviors in our daily life activities. So, it is possible to claim that subjects who adopt good postural behaviors present fewer chances of developing musculoskeletal disorders and therefore fewer postural changes.

When it comes to children, Kisner and Colby [17] claim that good postural behaviors prevent adaptive changes from muscles and soft tissues by avoiding the overload of growing stage bones.

In order to keep a healthy and free of pain body, especially when it comes to spine area, it is important to maintain an ideal posture alongside with regular physical activity practice. On the opposite side of the spectrum, a bad posture, sleep disturbances and stress are the main risk factors that contribute to pain episodes.

Bad postures, according to Mota [18] contribute to what he dubs as postural insufficiency, suggesting an early preventive intervention in school environment as the way to avoid this behavior.

Development deviations is the expression associated with most of postural deviations that happen in growth stage children, it is when this pattern develops into an habit that may lead to postural shifts [19, 20].

In order to minimize chronic musculoskeletal disorders occurrences in adulthood, especially on spine area, Knoplich [21] claim the necessity to realize preventive behaviors orientations to children and adolescent.

Although it is mandatory for us to question society, especially parents, teachers and guardians, preparation and consciousness about the meaning of this preventive measures, since the lack of information may cause the arising of postural changes in children and adolescents.

Although it is important to highlight that one of the reasons that contribute to parents, teachers and guardians' lack of knowledge, when it comes to postural behaviors, may due to the absence of preventive orientations in school environment [4, 22].

Are we able to consider postural behavior education in school environment, through the development of preventive strategies around children and adolescents, in order to allow them self-body awareness, especially when it comes to their spine? Would it be coherent to incorporate the teaching of this strategies in Physical Education curricula, in order to allow teachers to proactively contribute to children and adolescents' self-body awareness?

Barbosa [23] alongside with Ramos and Rodrigues [4] consider that the role of physical education teachers involves contributing to their students' lifestyle healthy habits through plain observation. This strategy would allow him to identify and possibly relate triggering reasons or aggravating postural behaviors, in order to correct them. It is expected from him the capability to eradicate bad postural habits, by providing his students with spine pathologies' related preventive measures.

When analyzing Physical Education curricula, it is not possible to find any postural education strategies contemplated in their program. This may be seen by the lack of any postural muscular strengthen and self-body awareness exercises [2–4].

Good postural behaviors and self-body awareness content are depreciated by jokes, games and competitions when it comes to a much more precise analysis of Physical Education curricula [2–4].

It is widely known that teachers play a key role in children and adolescent growth development. This should be one of the main reasons for them to incorporate in all subjects curricula preventive activities and early spine postural deviations detection strategies [2–4].

Back School by Zachrisson [24], originally developed in 1969 and considered to be one of the mainstream postural preventive strategies, aimed to prevent musculoskeletal back pain problems in adults. Applied in three or four one hour meetings, this program was taught to children and adolescents that had already experienced spine musculoskeletal problems. This program incorporating anatomy, spine biomechanical, pathophysiology, ergonomical and postural knowledges provided students with daily life, stretching, strengthen and relaxation strategies.

Applied by Cardon et al. [25] to the school context, they approached the ideal posture while seated, weight lifting and transporting, while at the same time highlighting preventive measures adoption while physical activity practicing. Their results showed that Back School originated immediate changes when it comes to the adoption of good postural behaviors, since the subjects presented higher theoretical and practical results, even after a few months follow-up study [25–27].

## 2 Methodology

### *2.1 Aim*

This paper aimed to present a study that analyzed the relation between musculoskeletal disorders and postural habits adopted by 5th and 9th school grade students, from both sexes.

This 5th and 9th grade population was chosen according to two different school periods, the entrance and exiting level for the third Basic Education Cycle, this dues to our intent of seeing if there was already possible to find any postural changes in both of this stages.

## 2.2 Study Sample

Dating from July 2013, there were 1532 students enrolled in the school, 760 of which attending the 2nd and 3rd Basic Education Cycle, of whom 282 were in the 5th and 9th grade (151 and 131, respectively).

This study population, as mentioned earlier, represent the beginning of the 2nd Basic Education Cycle (5th grade) and the end of the 3rd Basic Education Cycle (9th grade), which were chosen in order to establish if there were already postural changes, or even spine musculoskeletal related problems, by analyzing and comparing pain complaints in both school periods.

Our sample consisted of 116 male and 104 female subjects, divided in 118, 5th grade and 102, 9th grade students, with ages between $10.6 \pm 0.7$ and $14.7 \pm 0.7$ respectively.

Approved by the ethical comity of Human Motricity from Leiria Politecnical Institute research center, this study asked for informed consents for students' parents and guardians. All of our procedures followed the Helsinki Declaration, to what human related studies should comply.

## 2.3 Procedures

This study have taken one month from participant selection process, personal identification questionnaire fill, musculoskeletal pain assessment according to Corporal Discomfort Scale [5] in order to verify and categorize the pain felt (where 0 corresponded to no pain and 5 to the full amount of pain felt by the subject), and its duration (acute pain—under one month, subacute—from 1 to 3 months, and finally, chronic pain—over a 3 month period).

In order to assess postural changes, an informal questionnaire was conducted, based on the work made by Carmo and Ferreira [6] and Rebolho [7], it pointed out pain body placement while in a seated, upstanding and backpack and weight carrying.

SPSS, 20.0 version was used in order to treat all the statistical data, for normality verification Kolmogorov-Smirnov test was applied before a descriptive analysis. This last, was calculated based upon standard methods. In order to analyze any characteristically difference between both groups, the *t* test was applied. In order to find variable relations Pearson's correlate coefficient (r) was applied. The statistically level of significance was establish in $p \leq 0.05$.

# 3 Results and Discussion

Body Discomfort Scale allowed us to find that, between a 0 (no pain) and a 5 (maximum pain) episode among the 220 subjects, there was a mean of 2.40 ± 0.96 that correspond to a moderate or severe episode. When it comes to pain episodes duration compared with their own intensity, our study allowed to find that with episodes duration increments comes intensity increments as well, as we may see by the 39.2 % of the subjects that claim to suffer from chronic pain (2.59 ± 0.87) and 2.57 ± 0.77 and 2.09 ± 1.09 corresponding to subacute and acute episodes, respectively. This allows variables correlation of acute and subacute episodes of $p = 0.02$ and acute and chronical ones of $p = 0.009$, although there was not any kind of relation between the subacute and chronic episodes, as we may see by the $p = 0.93$.

When it comes to musculoskeletal pain occurrence, 67.3 % (148) of the subjects claim to have experienced some episode, in at least one body area. From these, 53.4 % (79) claim to have experienced pain in two distinctive body areas while 27 % (40) claim to have felt it in three or more of this regions.

Considering its placement, 54.7 % (81) point out the spine region, 6.1 % (9) the head, 34.5 % (51) lower limbs, and finally, 4.7 % (7) upper limbs as the main problematic areas of pain occurrence.

Considering the aim of this particular paper, musculoskeletal pain occurrence between the 5th school grade students was 74.6 %, with an average intensity of 2.33 ± 1.0 (as it may be seen in Table 1). When it comes to its duration, 27.3 % of the subjects claim to have experienced chronic episodes, 47.7 % acute, while 25 % subacute episodes of pain occurrence. On the other hand, when it comes to 9th grade school age children (3rd Basic Education Cycle ending) the amount that claim to have experienced some kind of pain occurrence decreased (58.8 %), but the average pain intensity (2.50 ± 0.89) and its duration (56.7 % chronic, 21.7 acute and 21.7 subacute episodes) increased, as we may see in Fig. 1.

Gender analysis showed a mean experienced pain value higher in females (2.57 ± 0.93) for both school grades, considering 5th graders (n = 57, 48.3 %) with 2.49 ± 0.99 and 9th graders (n = 47, 46.1 %) with 2.69 ± 0.83 when compared to male subjects that presented a mean experienced pain value of 2.18 ± 0.97, where the 5th graders (n = 57, 48.3 %) showed a 2.49 ± 0.99 discomfort and the 9th graders (n = 55, 53.9 %) a 2.24 ± 0.92 (as it may be seen in Table 1).

**Table 1** Mean experienced values ± SD plus pain percentages by gender and school grade

| Gender | 5th grade | 9th grade | Total |
|---|---|---|---|
| Male | 2.15 ± 1.01 (51.7 %) | 2.24 ± 0.92 (53.9 %) | 2.18 ± 0.97 (52.7 %) |
| Female | 2.49 ± 0.99 (48.3 %) | 2.69 ± 0.83 (46.1 %) | 2.57 ± 0.93 (47.3 %) |
| Total | 2.33 ± 1.01 | 2.50 ± 0.89 | 2.40 ± 0.96 |

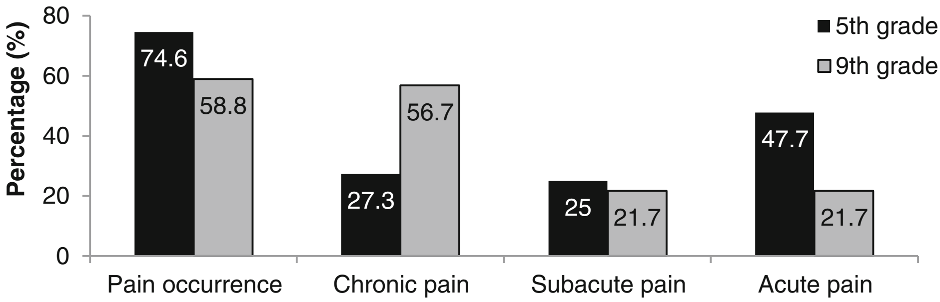


**Fig. 1** 5th and 9th grade episodes duration of pain comparison

Comparing the mean intensity of pain perceived by both genders, significant differences ($p < 0.001$) were found, for both school grades (5th grade, $p = 0.01$; 9th grade, $p < 0.001$) but when comparing both school grades with each other ($p = 0.15$), this study found no significant differences between them.

Regarding postural habits, 88.5 % of the participants that claimed to adopt bad postural ones, presented a mean experienced pain intensity of $2.44 \pm 0.97$, significantly higher ($p = 0.004$) than the ones that claimed to adopt good postural habits, with $2.06 \pm 0.82$ mean experienced pain intensity episodes.

## 4 Conclusion

This paper, besides serving as a theoretical foundation for postural education matter regarding school context, sought to present the first stage of a study developed in school environment with students from 2nd and 3rd Basic Education Cycle in Portugal, in order to raise the awareness around postural behaviors especially in school age children.

Its intent, for considering postural education as a fundamental part of Physical Education curricula, may lead to well informed children regarding ideal postural habits, that my prepare them better for their life ahead. School age children postural education should be seen as a priority fact in Physical Education classes, since it tremendously contributes for their students' life quality.

Results here demonstrated are in line with the purpose of this study, since it was capable to show musculoskeletal pain and bad postural habits correlation when it comes to school age children attending the 2nd and 3rd Basic Education Cycle in Portugal.

Major findings point out for a moderate to severe pain prevalence in subjects with bad postural habits, of whom we are able to highlight female, and older participants. When it comes to older (9th grade students) our results allowed to present a higher chronicity level of pain, especially among female subjects.

This study highlighted a few musculoskeletal pain causes, while raising the awareness for this theme in future studies to come.

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# Design and Evaluation of an Arm Support for Prevention of MSDs in Dentists

**Shaygan Hallaj and Sareh Sadat Moosavi Razi**

**Abstract** Based on the previous study among the dentists in India; neck, shoulder and back are at high risk of Musculoskeletal Disorders (MSDs). The same study suggests that, providing an arm support does have direct effect on reduction of pain in high risk areas. The purpose of this study is to design an arm support (extension) to fulfill this need. Various geometries of dental chairs have been considered to make sure it is compatible with most of the unit chairs. A 3D CAD model has been created using CATIA. This model is fabricated with a plastic 3D printer. Model has been created in such a way to get attached to the head rest of dental units. Dentists with high risk of MSDs were shortlisted from previous study. This population is used for evaluation of device. RULA ergonomic assessment is calculated to support the observation.

**Keywords** Musculoskeletal disorders (MSDS) · Ergonomic arm support · RULA · 3D printing · Dentist

## 1 Introduction

The prevalence of musculoskeletal complaints among dentists, like among other health care workers, is high and it is well documented [1]. Human-factors engineering and ergonomics play a crucial role in the pursuit of operational excellence and patient safety in healthcare [2]. Industrial musculoskeletal injury (MSI) prevention initiatives require risk assessment tools which accurately identify

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jobs at increased risk for injury. Traditionally the assessment of exposure is performed based on observation [3]. To manage and control physical ergonomic risks, several methods have been developed for assessment of exposure and estimation of risks of injury in various occupations [4]. The importance of usability engineering for medical devices has been more widely recognized since the publication of medical devices and applications of usability engineering to medical devices. Both the design and use of medical devices affect patient safety and the quality of care; both issues are a concern and priority internationally [5]. Poor working postures generate high static loads (increased muscle tension). It creates musculoskeletal discomfort or fatigue in the neck, shoulders, upper back and also work-related injury among professionals [6–9]. Proper ergonomic design is necessary to prevent repetitive strain injuries, which can develop over time and can lead to long-term disability. Literature suggests that the prevalence of musculoskeletal pain among dentists, dental hygienists and dental students ranges 64–93 % [10]. Usually General Dentists (GD) work deep inside the patient's mouth. They will tend to have a more awkward head, neck and torso posture. It enables them to view and work with better precision inside the patient's mouth [9]. Our previous study suggests that there is a need for change of body posture. This can be achieved by using a proper body support or by change in work area. A primarily design had been suggested for overcoming this problem in our previous study. Thereon, further changes have been incorporated in the original design with respect to improvement in the performance of the device. Thus, the objective of this paper is to further investigate the impact of the designed device while making major enhancements in the body posture of dentists.

## 2 Methodology

In this study 29 dentists have participated. 21 dentists were detected with high risk of MSDs. Based on our earlier study, it was concluded that the mentioned population of dentists need an immediate change in work postures and work tool design. All the dentists were called to work with the new designed device. Dentists worked with the device for duration of one week. Photos of dentists while working were captured from side and front view as well. These participants were asked to fill in a feedback questionnaire. The questionnaire included demographic questions such as gender, age, number of years of experience, hours of working per day and daily hours of exercise. The questionnaire was divided in two sections i.e. before and after use of device. Based on the collected data, customer satisfaction analyses are done. Suggestions and feedbacks of dentists about the design are summarized. Based on photos captured, Rapid Upper Limb Assessment (RULA) score calculations are done.

# 3 Design Process

## *3.1 Design Assumption and Challenges*

While designing the arm support, several parameters and constraints have been considered. The foremost priority is to create a device which is easy to install and remove from the workstation. Moreover, the installation of the arm support should not require major changes to be made in dental unit chairs. Another major constraint is the space available for connecting the device to dental units. Since it was considered that arm support should be attached to the upper part of the dental unit, there is paucity of space (average of 1500 $cm^2$) to design the attachment (Fig. 2). Device should not cause disturbance or distraction for dentists while practicing. If device attachment is too large, it can enter the space where dentists' legs rest. Same can be said about patient's head. One more challenge for design of such an attachment is the usage of dental unit chairs of myriad shapes. Head rests on dental units have different geometries and dimensions. It is a tedious task to design a device that has universal acceptability.

## *3.2 Design Assumption and Challenges*

For design, various ergonomic characteristics have been taken into consideration. Arm length of a dentist and head size of a patient are the vital factors. Arm support should not be too close to the patient's head. If it is too close, it can make the dentist's practice difficult. It can also cause discomfort for the patient as well. Based on data collected and ergonomic tables, a CATIA model is created (Fig. 1). The designed arm support has three main components: unit attachment, adjusting part and arm support. A model is printed with help of a 3D printer. Model is created with fused deposition modeling (FDM) technology and made of polylactic acid

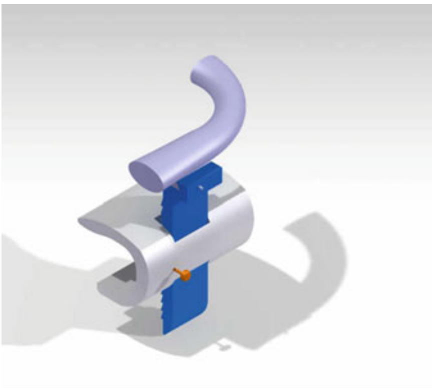

**Fig. 1** Dentist arm support device

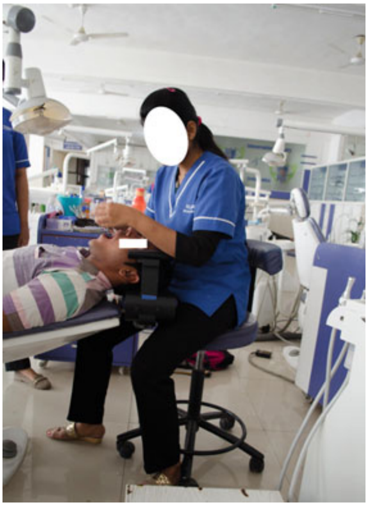

**Fig. 2** Dentist ergonomic body posture while using designed arm support

(PLA) polyester. Attachment part is printed with 40 % fill and rest of the parts is printed with 65 % fill. Two stripes of PVC fabrics with thickness of 4 mm each are attached inside the attachment, to prevent slipping of device (Fig. 2).

## 3.3 *Design Feedback*

Device is given to dentists to work with. Table 1 summarizes the overall evaluation of the device based on observation and feedback of the dentists.

**Table 1** Pros and cons of designed device

| PROS | CONS |
|---|---|
| It can be attached on most of units | Handle surface should be more flat |
| It does not interfere with legs of dentist | Angle of handle should reduce from 90 to 75° to increase comfort for dentist |
| It is not in view sight of patient | A cushioning surface needed on handle |
| Height adjustability is within working range | Upper part of attachment needs to be modified for patients' head to make it more comfortable |
| It is easy to work with | Size of attachment to be reduced |

*Source* Primary data

Based on our observations, dentists preferred to have only one side arm supported. For example, right handed dentist are more comfortable to use left hand support and vice versa

## 4 Customer Satisfaction Analysis

Questionnaires were distributed among 29 respondents out of which 14 are males and 15 are females. Average age of data sample is 27 years. Their average working experience is 4 years and average working hours is 6. Same dentists' population is exercising 19-min in average every day. Tables below are showing the dentists response for work place and body posture before and after using the designed device. Out of 29 respondents, 21 respondents have higher risk of MSDs. Photos of dentists are taken while working with the device. Their body posture analysis is calculated with RULA (Rapid Upper Limb assessment) and its average value is 3.14. This number illustrates that the arm support has made significant changes in dentists' body posture. This posture can further be improved by adjusting both the patients and dentists chair, to support the dentists' neck during work.

Figure 3 shows that the combined bending and twisting of back has decreased by 13.79 % after using the device. It can be seen from the same table that, "Any Visible Back Bending" has decreased by 58.62 %. Whereas "Twisted More Than 20 Degree" section has reduced by 13.79 %. "Bend forward or Sideways More Than 20 Degrees", there is 10.34 % decrease after using the device.

From Fig. 4 it can be seen that, in the cases of "*Bend and Twisted*" *and* "*Bent Backward*" there is no difference between before and after using designed device,

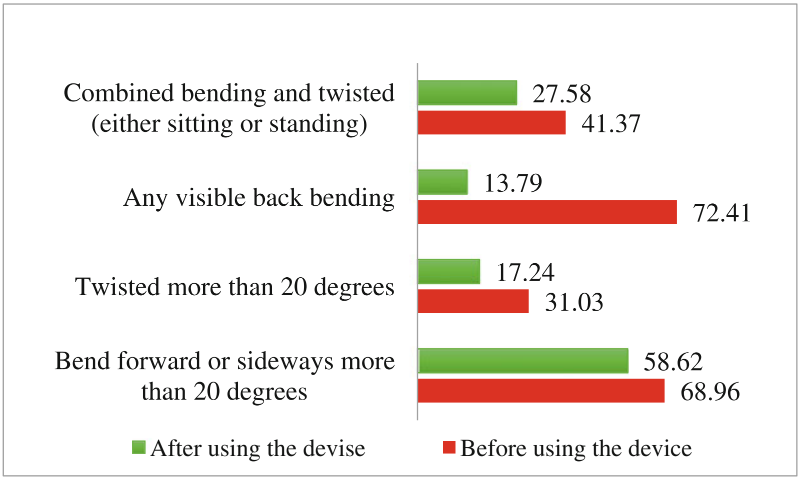


**Fig. 3** Body posture performance for back

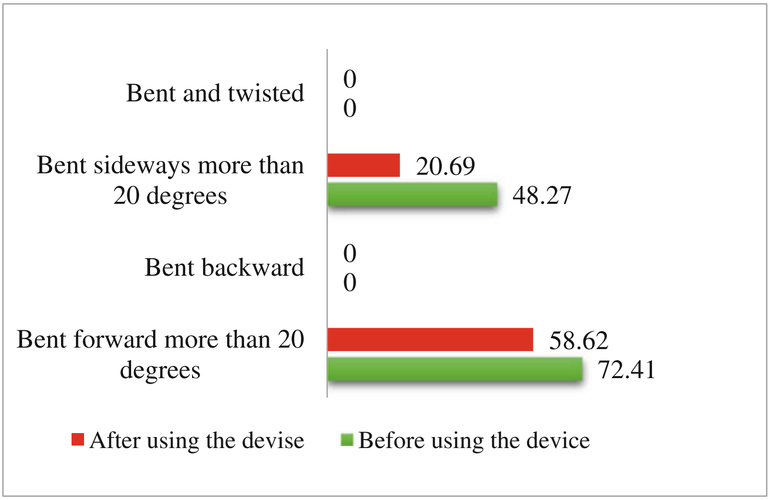


**Fig. 4** Body posture performance for head and neck

but there is a 13.79 % decrease in the case of "*Bent Forward More Than 20 Degrees*". Also there is a 27.58 % decrease in "*Bent Sideways More Than 20 Degrees*" after using device.

Figure 5 shows; there is an increase of 31.04 % in "*With Elbows out to Side*", 6.9 % in "*Beyond Forearm Length (30 cm) in Front of the Body*" and 68.96 % in "*Without Support for the Forearm and Elbows*". Also from the table it can be seen that, there is no change in "With Arm Reaching behind the Body" after using device.

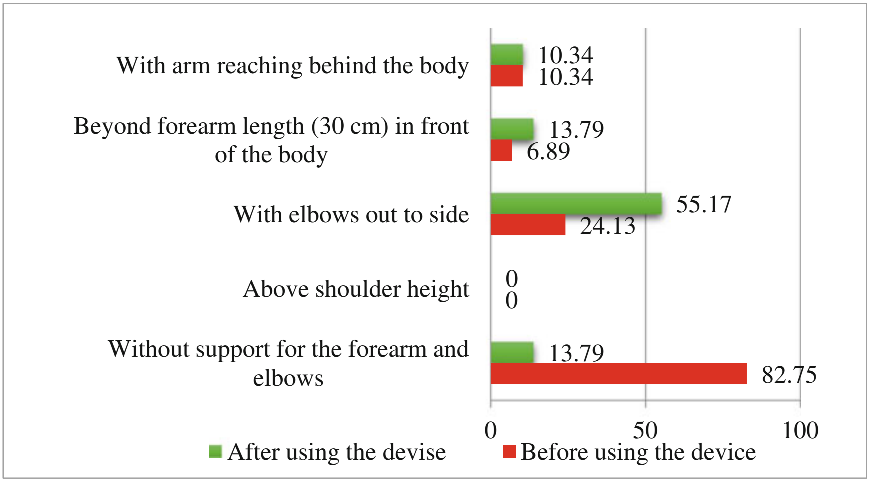


**Fig. 5** Body posture performance for arms and shoulders

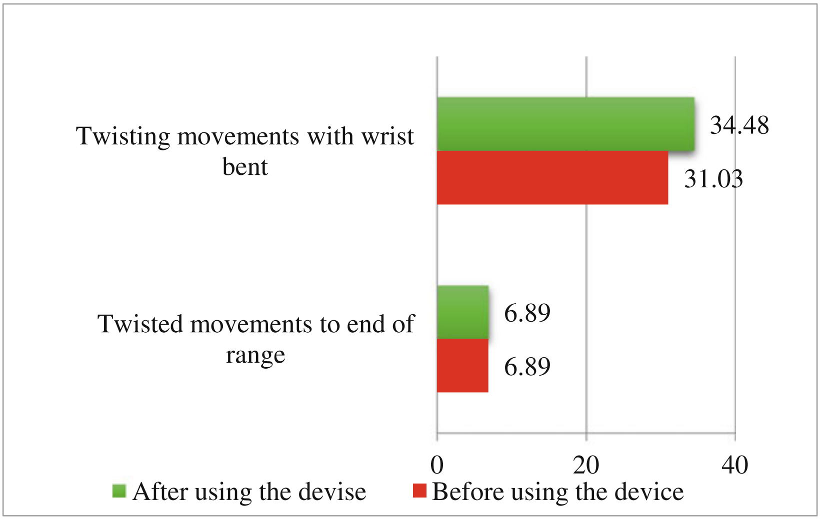


**Fig. 6** Body posture performance for elbow and forearm

Figure 6 indicates 3.45 % increase in "Twisting Movements with Wrist Bent". Also as per table, there is no change in "*Twisted Movements to End Range*" after using device.

Figure 7 shows 20.69 % decrease in "*Twisting, Turning, Grapping, Wringing Actions With Fingers Or Arms Bent*", 6.89 % decrease in "*The Fingers Bent with*

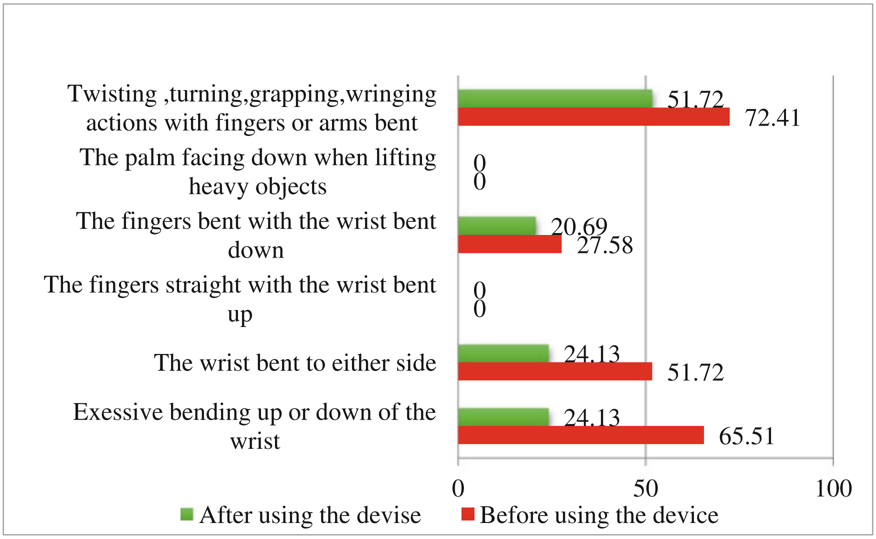


**Fig. 7** Body posture performance for wrist and forearm

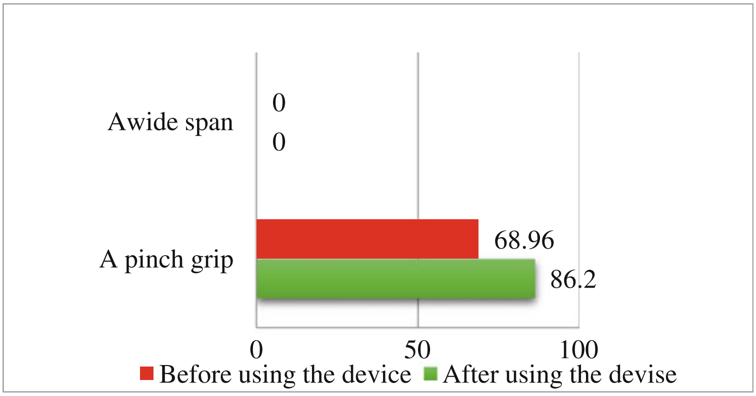


**Fig. 8** Body posture performance for wrist and forearm

**Table 2** RULA assessment calculation

| Respondents | RULA score |
|---|---|
| 1 | 3 |
| 2 | 3 |
| 3 | 3 |
| 4 | 4 |
| 5 | 4 |
| 6 | 5 |
| 7 | 3 |
| 8 | 3 |
| 9 | 4 |
| 10 | 2 |
| 11 | 3 |
| 12 | 4 |
| 13 | 4 |
| 14 | 2 |
| 15 | 3 |
| 16 | 4 |
| 17 | 2 |
| 18 | 2 |
| 19 | 2 |
| 20 | 4 |
| 21 | 2 |

*Source* Primary data
Final RULA Score
*1–2* Acceptable
*3–4* Investigate further
*5–6* Investigate further and change soon
*7* Investigate and change immediately

*the Wrist Bent Down*", 27.59 % decrease in "*The Wrist Bent To Either Side*" and also 41.38 % in "*Excessive Bending Up or Down of the Wrist*". From the table it can be seen that, there is no change in "The Palm Facing down When Lifting Heavy Objects" and "*The Fingers Straight with the Wrist Bent Up*" after using device.

Figure 8 indicates that there is 17.24 % decrease in "A Pinch Grip" and there is no change in "A Wide Span".

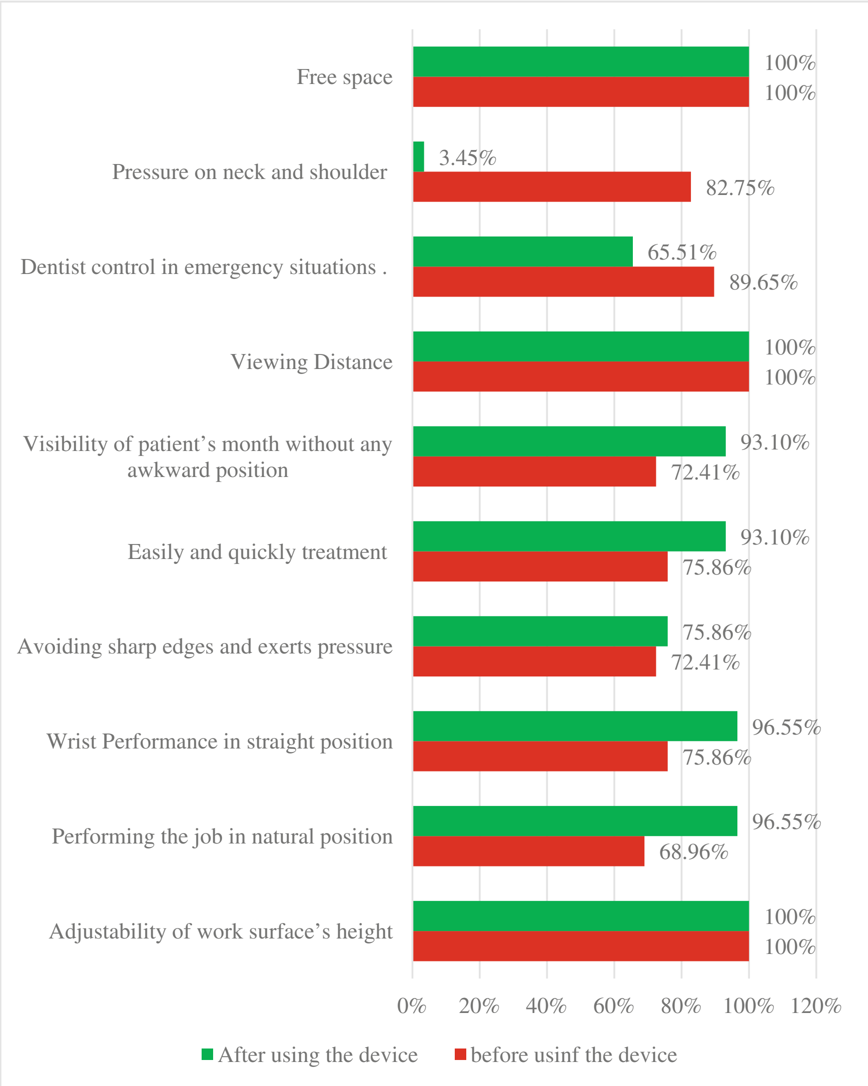


**Fig. 9** Work place checklist comparison

To support the dentists' experience before and after using the designed device RULA was calculated.

Table 2 indicates that, the average of scores calculation by RULA employee assessment worksheet is 3.14 which indicates that, the dentists are working in a posture that could present some risk of injury from their work posture, and this score most likely is the result of one part of the body being in a deviated and awkward position, so this should be investigated and corrected [11].

## 5 Comparison of Work Place Checklist

Figure 9 results indicate that there is significant difference between before and after scenarios of using the new device. Overall it can be concluded that, the designed device is having a positive impact on work place.

## 6 Conclusion

From customer satisfaction analysis, dentists have more comfort by using the device. The result extracted from RULA indicates that by using designed device, the body posture is almost in the correct ergonomic position. On the other hand from observations we can conclude that, neck should be in a better position by adjusting both dentist's and patient's chair. From this study it can be established that, the designed device is useful to decrease the risk of Muscular Skeleton disorders as it provides support to hands and shoulders of the dentists, thus reducing the muscle stress on the upper body. Further design improvements are been made to give even better results. Hand support angle are being made adjustable relative to dental units. Universal attachments are to be improved. A suction holder can be added on the side of the handle.

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# Participatory Ergonomics Management in a Textile Thread Plant in Brazil Employing Total Quality Management (TQM) Tools

**Carlos Maurício Duque dos Santos, Rosangela Ferreira Santos, Andréa Ferreira Santos and Mariana de Castro Moreira Rosa**

**Abstract** Although this paper introduces a study on the implementation of a Participatory Ergonomics Management system using TQM (Total Quality Management) tools, aimed at adapting work stations, the workplace and work conditions in order to comply with Brazilian Labor Legislation. The management system implemented is based on the concepts and principles of Participatory Ergonomics, in which the system users are, namely, the company employees at varying hierarchical levels. As part of this system, all social actors involved take part in operational decisions and implement the ergonomic adaptations in production processes, workstations and in the organization of work, in a democratic and participatory manner. The paper presents the methodology for implementing the management system, from the dissemination of Ergonomic expertise among all those involved (internal company team), to the control of the implementation process with gauging of results for each ergonomic action, based on Ergonomic Regulatory Standard NR-17, part of Brazilian Labor Legislation and mandatory for all companies. Note that the Participatory Ergonomics Management system in question is implemented in a large textile thread plant in Brazil and was initiated in April 2012. It continue to run presently (March 2016) and has been frequently audited. Results are significantly positive in all production sectors due to employee health benefits and the optimization of production processes. It has earned three internal company awards, two in the production unit and one international award from the company's business units in Latin America.

**Keywords** Participatory ergonomics management · Textile thread · Total quality management

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# 1 Introduction

The standard was known as NR-17 [8] for Ergonomics from the Ministry of Labor and Employment, and which still in effect and has, in recent years, become a point of inspection by Labor Inspection Agents (professionals from the Ministry of Labor and Employment that inspect companies to ensure compliance with the standard).

On the other hand, companies face a series of obstacles in fulfilling this Ergonomics standard (NR-17) for a number of reasons, including a lack of qualified and skilled professionals to conduct Workplace Ergonomics Assessments (WEAs). And, when such a professional is found to implement the WEA, the person is unable to implement the recommendations by the ergonomist that prepared the WEA, it always falling on an outside professional to implement said recommendations. This is one of the reasons that work stations and workplace conditions fails to comply with NR-17 [8] for Ergonomics, which leads to further problems for the company and employees, as there is an increase in the number of employees with early set-on illnesses, more accidents, more absenteeism and, consequentially, higher costs, lower quality, lower productivity and less competitiveness.

Faced with this, with our experience of almost 40 years involved with Ergonomics within the most varied industries, implementing Workplace Ergonomics Assessments and developing Work Station Ergonomics Projects to comply with Ergonomics legislation (NR-17) from Brazil. In addition to our academic experience of 25 years administering Ergonomics lectures in undergraduate and graduate program in Brazilian universities and having studied a master and doctoral program in Production Engineering with a major in Ergonomics, it was decided to create a Participatory Ergonomics Management model at the company. The Participatory Ergonomics Management model, forming the subject of this paper, certainly suffers from limitations in terms of scope at the outset. However, it is a useful and practical model that is easy to implement, which contributes to its adoption by medium and large companies and, more importantly, with short- and medium-term results for some actions and long-term results for others, which makes it viable for a company of any type and size.

## *1.1 Social Relevance and the Contribution of Participatory Ergonomics Management*

In recent years, it has been noted a significant increase in occupational disease in Brazil, both within office environments and in production sectors in factories, especially those in which manufactured goods depend highly on human involvement in the process, whether through manufacturing/handling the product or in the control of the actual product process. In manufactured goods factories, due to ergonomic inadequacies in the manufacture/handling of products, production methods and general workplace conditions, the risk of developing an occupational disease is high, especially Musculoskeletal Disorders, or RSI/MSDs (Work-Related Repetitive Strain Injury/Musculoskeletal Disorders). The majority of companies from this segment (product manufacture) have a high rate of occupational disease and many employees are absent due to occupational disease, especially through RSI/MSDs, which results in high costs for companies, as well as lower quality and productivity.

The great majority of companies are still unaware of the real benefits of ergonomics in optimizing productive processes and general work conditions and restrict Ergonomics to a simple and limited ergonomic assessment using Ergonomics tools, such as the NIOSHI model and the RULA, REBA, OCRA, Moore and Garg, and Suzan Rogers methods, among others. These are merely aimed at identifying and quantifying biomechanical aspects of the task activities, and do not point out other ergonomic problems within the workplace, which include Environmental Comfort, Work Organization, problems and inadequacies of Machines and Equipment, Furniture and Accessories, and, chiefly, the psycho-social aspects at work.

The aforementioned ergonomics tools do not consider the necessities and difficulties operators face in conducting their tasks, as these methods do not consider their perceptions, opinions and sentiments with regards to their tasks. This may hide or mask a series of bio-psycho-social and technical-operation problems at work, which truly contributed to the companies' lack of awareness of these problems and consequentially makes it impossible to find comprehensive and holistic solutions to them. Due to the reasons described above, the principles and concepts of Participatory Ergonomics were selected (in which the participation of professionals from all hierarchical levels and all sectors involved in the process) to create an Ergonomics Management system, while also discussing aspects recommended by NR-17 for Ergonomics by the Ministry of Labor. As such, the scope of the assessment becomes more objective and systemized and offers a wider and more encompassing overview, as all those involved take part in the diagnosis and also in the solutions. To meet these needs, it was necessary to create a Participatory Ergonomics Management system considering the aspects recommended in NR-17 for Ergonomics, through which it is possible to diagnose ergonomic problems in terms of physical, cognitive and organizational scope and the different types of applications of Ergonomic expertise (Conception, Correction and Conscientiousness) in a participatory manner, that is, with the participation of all company employees, involved from upper management down to the simplest operator. With this strategy it was possible to identify all the problems, difficulties and needs of the operators, supervisors, management and senior management and, using this identification, prepare a program with specific and general interventions to improve work stations, production processes and work conditions with criteria established by all involved, in a way to ensure mutual benefit, for both employees and the company.

With the implementation of the Participatory Ergonomics Management System at the textile fiber production unit, forming the subject of this paper, the gains and benefits were significant and comprehensive during the 3 years it was used:

- Reduction in absenteeism and labor costs;
- An end to injuries among employees;
- A drop in medical aid claims;
- Improved work conditions;
- Improvement in the work environment;
- Happier and more satisfied employees;
- Improvement of the company's image among public entities;
- Protect the company from future labor suits.

## 2 Contextualization of Ergonomics and Its Benefits to Companies and Employees

Dull [1] outlines the social meaning of Ergonomics… "Many situations in work and daily life are harmful to our health. Musculoskeletal disorders (especially lower back pain) and problems stemming from stress, constitute the most important cause of absenteeism and an incapacity for normal and regular work. These situations may be attributed to poor design and incorrect use of equipment, systems and tasks. Ergonomics can contribute to reducing these problems. Once this was recognized, many countries have obliged health services to employ ergonomists".

To Karwowski [2] Ergonomics, also referred to as *human factors*, is a scientific subject that deals with interactions between humans and technology. Ergonomics is part of the knowledge on human sciences used to adapt tasks, systems, products and environments to the skills and physical and mental limits of people. "Karwowski [2] goes further and we find a contemporary contextualization of ergonomics as being…" a disciple that focuses on the nature of interactions between humans and items, based on the unified perspective of science, engineering, design, technology and the management of human-system compatibilities, including a variety of products, processes and natural and artificial environments.

In the words of Karwowsky mentioned above, evidence of the holistic and comprehensive view of Ergonomics can be seen, which creates space for the implementation of improvements in product quality, workstations, and the production processes, especially in terms of ergonomic quality assessments with an emphasis on usability.

According to Daniellou and Nael [3] "the improvement of work conditions and the design of technical devices adapted to human characteristics, based on the criteria of ergonomics, has a dual objective. The first refers to the comfort and health of operators. This includes the prevention of accidents and disease risks linked to work and in seeking to reduce, as much as possible, all sources of fatigue, whether they be associated to the metabolism of the human body, muscle and joint stress, or the cognitive requirements of work (processing information, solving problems). The second objective of Ergonomics aims for effectiveness in the use of a product or in the operation of a production system, which may be jeopardized by inadequate or excessive human function requirements".

In Iida [4], p. 18: it reads… "The scope of Ergonomics expanded significantly as from the 1980s. This amplified version was also referred to as macroergonomics. According to this new vision, Ergonomics is defined as "*development and application of human-machine interface technology at a* ***macro*** *level, that is, throughout the whole organization*". Nowadays, a whole company, which may involve thousands of workers, is considered a global system, which must be studied as a whole". As such, Ergonomics has began to participate in the design and management of organizations. This activity is referred to as ODAM—*Organizational Design and Management*.

There is a correlation between Quality of Working Life and Ergonomics when stating… "The definitions of Quality of Working Life range from medical care established through health and safety legislation to voluntary activities for employees and employers in the areas of leisure, motivation and innumerous others. The majority of these paths lead to a discussion on the living conditions and well-being of people, community groups and even the whole planet and its insertion within the universe. In fact, the base of discussion about the concept of life quality includes choices on well-being and perception of what can be done to meet expectations created both by managers and users of actions of Quality of Working Life in companies". It is noted that…"adaptation of work to humans has been considered by Ergonomics with a base on physical, cognitive, environmental and psycho-social means. The growing—and continuously faster—evolution of technology has been making work more complex and calls for people with higher qualifications…. The organization of human work has also been considered one of the elements in ergonomic analysis and design".

To Abrahão et al. [5], (p. 19): "Generally speaking, ergonomics can be understood as a discipline with the goal of transforming work, in its different dimensions, adapting it to the characteristics and limits of human beings. In this sense, ergonomics surpasses Taylor's concept of 'Homo Economicus', showing the limit of the reductionist point of view in which only physical work is considered, revealing the complexity of working and the multiplicity of factors that comprise it."

Further to Abrahão et al. [5], (p. 19): "Despite the fact that much expertise is already consolidated by ergonomists, not all have been effectively appropriated by society. Thus, nowadays, it is still common to receive demands that, for example, cite the height of counters, parameters for the acquisition of chairs, among others. One should not shrink from catering to them as, quite often, they are the tip of the iceberg. It is through them that is possible to unveil and explain the other dimensions of work responsible for issues relative to health and production".

To Santos [6] Whatever the scope and ergonomic focus of the workstations, it must meet the following objectives: adapt the work station to the limits and capacities of the individual, either physically, psychologically or cognitively; improve work conditions to leverage effectiveness, efficiency, productivity and quality in operations; provide conditions for the development of creativity and participation of employees/collaborators; avoid human error, prevent occupational accidents and diseases and provide comfort, safety, quality of life, well-being and satisfaction at work.

According to Braatz [7] "The great majority of authors that discuss ergonomic actions cite the importance of validation as a stage or means of assessment, verification and/or restitution of knowledge among employees from areas subject to the intervention".

The same author goes on to say: "The duality of Ergonomics, according to a definition by the International Ergonomics Association (IEA), points out the comprehension of the relation between humans and other elements or systems in work environments (theory) and the application of principles, data and methods in projects to optimize human well-being and the overall performance of the system (practical) as the two facets that Ergonomics possesses. Validation plays a vital role in the duality presented, seeing that, through it, it is possible to discover the effectiveness of being put in practice and the validity of the knowledge generated".

In the opinion of Dejours [3], the quest for science in Ergonomics must begin through practice. And, if the priority of Ergonomics is the product of ergonomic action, its effective use lies in assessment of the results. That is, assessing the effective transformation of ergonomic action.

With conceptual and theoretical evidence explained by Braatz [7] the need for an assessment system becomes clear in order to gauge the contribution of Ergonomics to employees and to the company. In our understanding, an assessment of ergonomic action (on the work station and on the work conditions) is only possible with a Ergonomics management system at the company and, if possible, this system should be participatory (that is, relying on the effective contribution of company staff, especially in explaining their real needs and in the validation of ergonomic actions by users).

Based on the definitions, concepts and experiences cited above, it was noted the importance, the relevance and the indispensable and necessary contribution of Ergonomics and ergonomic technology in improving the quality of products, work stations and production processes, especially in terms of adapting the product, work station and production process to humans in general and to the operator specifically, that is, the adaptation of the use of the product to the user/consumer, the adaptation of the work station to the worker/operator, and the adaptation of the production process/work conditions to suit workers/operators.

As such, it seems like a clear and opportune moment to use ergonomic management models to be implemented in companies, which present improvement indexes with the implementation of ergonomic actions to comply with NR-17 for Ergonomics, with the tools that allow one to "view" before and after the ergonomic intervention as a way to "gauge the value" of the ergonomic action and, more than that, gauge the gains resulting from ergonomic action, among which are compliance with labor legislation (NR-17), as each item in NR-17 that is not met by the company is subject to a fine, as well as other costs resulting from a lack of Ergonomics. When speaking of "costs" it is understood that a reduction of "costs" is gauged as "gains and/or benefits".

In the series of approaches mentioned above by authors and experts, the point they all have in common is the benefits of Ergonomics, whether for the employees or the company. It is also clear that Ergonomic intervention must be widespread and comprehensive and, preferably, include the participation of all, when dealing with macroergonomic intervention. This justifies the creation and use of a Participatory Ergonomics Management System and its application in companies, as pointed out in this paper, which is a "case study" involving a textile thread manufacturing company.

## 2.1 The Participatory Ergonomics Management System Used at the Company

According to Iida [4]: "Participatory Ergonomics is the method through which ergonomics end users perform an active role in identifying and analyzing ergonomic problems, as well as in the formulation and implementation of solutions. It involves the training of employees and the organization of participatory groups".

To Iida [4] "Effective participation involves growing levels of knowledge acquisition, behavior changes and feedback control. This must occur continuously and cumulatively. It begins with an external regulation and evolves until reaching a self-sustained internal regulation".

The model for the implementation of a system for continued ergonomics improvement in work conditions uses the concept of Ergonomics of Participation of Participatory Ergonomics Iida [4] "that is, the company's COERGO (Ergonomics Committee) that assesses the work stations and implements ergonomic improvements from station to station". See a diagram of the participatory ergonomics implementation processes proposed in Iida [4] presented in Fig. 1 and consider the following definitions:

- *External regulation: represents the initial state, with practically zero internal participation. Up to this point, ergonomic expertise are only mastered by the external consultant, who is added to the program.*
- *Internal regulation: condition in which the members of the company begin to master essential ergonomics knowledge and are able to assume control of the processes, in a way that the external consultant can be let go.*

Due to the objectives of the model for improving ergonomic quality of workplace conditions, one of the most traditional quality tools was selected to prepare the Participatory Ergonomics Management System, namely the PDCA Cycle (Fig. 2), conceived by Walter Shewhart (Costa, Neto and Canuto 2010), widely promoted by Deming and Juran and which was duly used in the Japanese movement for quality, prior to it popularization in the West.

The PDCA cycle consists of 4 stages:

- PLAN: where the goal and method are defined;

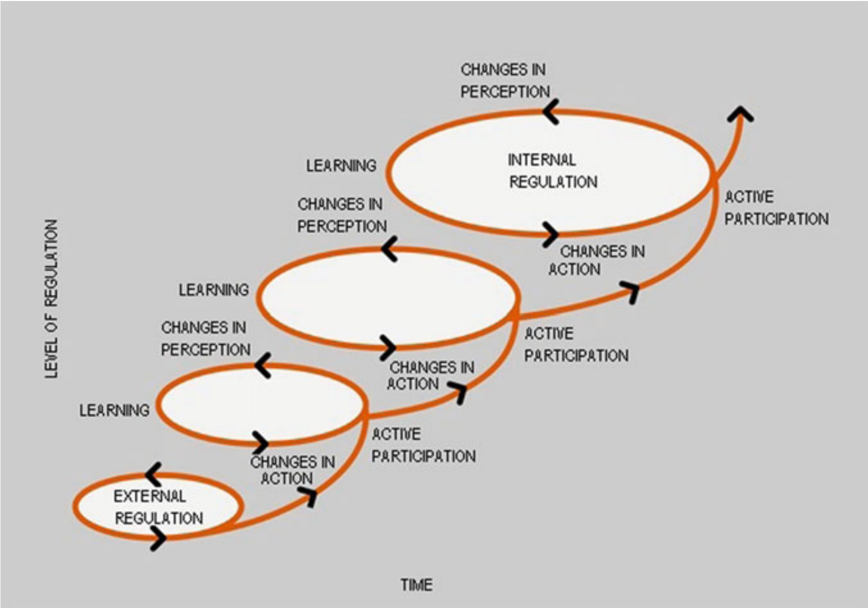


**Fig. 1** Regulation of the process for the implementation of participatory ergonomics in Iida [4]

**Fig. 2** Walter Sherwhart's PDCA cycle


- DO: educate and train, execute and collect data;
- CHECK: gauge results and compare them with the goals;
- ACT: implement corrective and preventative actions and improvements.

To "rotate" the PDCA Cycle, it is necessary to gauge, as only by gauging is it possible to improve continuously. As emphasized by Japanese quality guru Kaoru

Ishigawa, the model must thus have indicators for improvements in work conditions based on items from NR-17 for Ergonomics, to ensure effective improvements of work conditions and, consequentially, the satisfaction and well-being of employees in relation to comfort, safety and performance. To attain the objectives proposed in research, three sub-systems will be included in the participatory ergonomics management system, namely: technical aspects, human aspects and legal aspects. Each of these aspects has an area of scope as shown below:

- Human Aspects: consider the anthropometric characteristics of operators, biomechanical requirements in conducting tasks, physiological needs and characteristics of the operators in performing their tasks, psychological, cognitive and social aspects at work. The aforementioned human factors have the job of fulfilling the human needs in the conduction of tasks.
- Technical Aspects: consider the characteristics of machines and equipment, furniture and accessories, production methods and processes, work organization, physical facilities and environmental conditions. Technical aspects play the role of fulfilling the operational need to conduct tasks.
- Legal and Regulatory Aspects: consider the labor law requirements (NR-17 for Ergonomics and Technical Note 060-2001) and OHSAS regulation 18001: 2007, specific to Occupational Health at Work.

Legal and regulatory aspects are aimed at fulfilling labor legislation (NR-17 for Ergonomics), as well as the regulation of the company operational procedures in order to attain goals. As shown in Fig. 3, these three sub-systems interact, are integrated, are in synergy and call for continuous control, as any changes in one sub-system will impact the others.

## 2.2 *Operationalization of the Participatory Ergonomics Management System*

The participatory ergonomics management system proposed in this paper employs the Haims and Carayon's concept and principles for Participatory Ergonomics (Fig. 1), where the external regulation is overseen by an External Consultant (experienced ergonomist) and internal regulation is overseen by the Ergonomics Committee (internal company team).

**Functions of External Consultancy**: external consultancy is aimed at coordinating the implementation and operationalization of the Participatory Ergonomics Management System, using methods and techniques generated through scientific and technological expertise, as well as their experience in ergonomic action in different fields of operation and scope. In this specific case, external consultancy was responsible for: preliminary identification of sector and work stations, conduction of the Ergonomics Assessment on Word Stations to comply with NR-17 for Ergonomics and to provide the company with a list of ergonomic regulations to

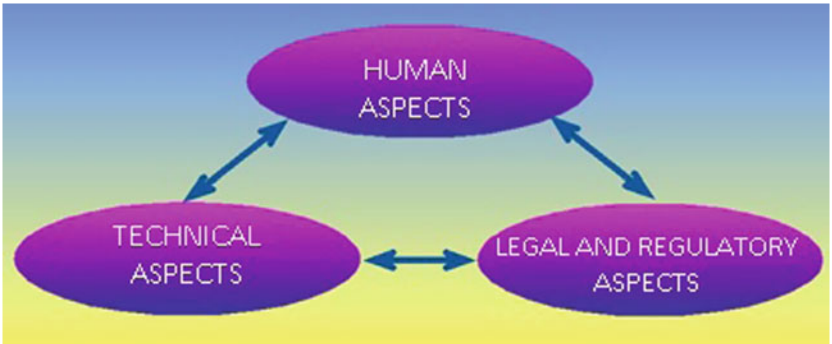


**Fig. 3** Diagram of participatory ergonomics management sub-system interactions

make ergonomic adaptations to work stations. Further, it was responsible for training the company's internal team, namely: steering committee, comprised of senior management and the operational committee, comprised of company technicians from both production areas and workplace health and safety.

**Functions of the Operational Committee (COERGO)**: implement the ergonomics checklist to comply with the diverse items of NR-17 for Ergonomics. In addition to identify ergonomic inadequacies at work stations and in production processes so as to identify the varying operational needs and those of workers at their places of work, while also contributing with ideas and suggestions for improvements provided by them and the actual employees from the work station.

**Functions of the Steering Committee (CODIR)**: to guarantee the implementation of the company Ergonomics Management System, meet the needs of External Consultancy and the Internal Ergonomics Committee (COERGO) in issues relative to the identification and solutions of problems. CODIR is formed by senior management from the company and presided over by the CEO and comprised of directors and technical and administrative technicians.

Figure 3 shows the systemization of external consultancy and Ergonomics Committee functions. To follow is a list of the main actions by External Consultancy and COERGO.

- **Internal Team Capacity Building (COERGO)**: training with 40 h of theory and 40 h of practice in ergonomics assessments to comply with NR-17 for Ergonomics in all items.
- **Mapping Production Line Work Stations**: included the identification of workstations and description of tasks and activities conducted at each point.
- **Ergonomic Assessment (NR-17)**: conducted by members of COERGO, using items from NR-17 for Ergonomics as a means to identify conformity with each item of NR-17. During the ergonomic assessment graphs and spreadsheets are drafted with the results for the stations, with:

1. Conformity Assessment Graph according to items of NR-17 for Ergonomics for each production line workstation;
2. Conformity Assessment Spreadsheet for each production line workstation;
3. Criticality Assessment Graph for each station in terms of conformity with NR-17 for Ergonomics.

- **Conception of the Ergonomic Action**: at this stage, the recommendations and suggestions for ergonomic adaptations are presented for each work station, based on the company's needs and resources and the necessities and priorities of the employees, who were analyzed and discussed by COERGO.
- **Validation of Ergonomic Action with Employees**: validation with employees is of vital importance to the ergonomic adaptation process and is implemented presenting the COERGO recommendation and suggestions for the adaptation in questions, so that employees take part and leave an opinion on the suggestions, even able to add to the suggestions and also present new improvement suggestions, there by implementing the participatory system.
- **Implementation of Ergonomic Action**: following the validation of ergonomic actions by employees, COERGO is responsible for the implementation of the ergonomic improvement at the work station or in the organization of work, thereby transforming the work conditions at the work station and in the production process.
- **Gauging and Assessing Results**: this stage is aimed at assessing the results of the improvements made and was held at least 12 months after the implementation of the ergonomic improvement, and covered all production line workstations, considering compliance with items from NR-17 for Ergonomics, using the same initial Ergonomic Assessment tools, including the preparation of grafts and spreadsheets, for a comparison of "before" and "after" the implementation of ergonomic improvements.
- **New Ergonomic Actions**: after gauging and assessing results, new ergonomic actions may or may not be required, thereby completing the cycle of the continuous improvement process.

## 3 Conclusions

The Participatory Ergonomics Management System has proven itself efficient in identifying ergonomics problems at work stations, in production processes and in work conditions and permitted the implementation of ergonomics actions recommended in the WEA—Workplace Ergonomics Assessment to comply with NR-17 for Ergonomics (conducted by external consultancy) and by the Ergonomics Checklist (conducted by COERGO). The ergonomic actions implemented made an effective contribution to adapting the work conditions at workstations and in production sectors, in accord with the requirements of the Ergonomics Regulating Standards (NR-17) part of Brazilian labor legislation. The Participatory Ergonomics

Management System also contributed through a range of benefits for both the company and employees, as mentioned by the company, namely:

- Reduction in absenteeism and labor costs;
- An end to injuries among employees;
- A drop in medical aid claims;
- Improved work conditions;
- Improvement in the work environment;
- Happier and more satisfied employees;
- Improvement of the company's image among public entities;
- Protect the company from future labor suits.

The Participatory Ergonomics Management System has earned 3 internal company awards, among them the 2015 Management Excellence award in the "Employee Benefits" category.

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# Can the Context Stigmatize the Assistive Technology? A Preliminary Study Using Virtual Environments

**Luciana Carneiro, Tiago Oliveira, Paulo Noriega and Francisco Rebelo**

**Abstract** Some studies report that aesthetics of Assistive Technologies (AT) as well as the emotional reactions that occurs when it is observed and used have great impact on stigmatization. In this scope, and based on the fact that the context influences the User Experience (UX) with AT, we are interested in investigate if the context influences the stigmatization of an AT, in particular a traditional wheelchair. It was developed a questionnaire with semantic variables related to aesthetic and emotional reactions, used by 46 university students when interact with two virtual environments with a wheelchair: a garden environment with people and other with the wheelchair only. We did not identify statistically significant differences between the two contexts for emotional and aesthetics variables. This preliminary study points the need to develop more studies related with the influence of the participant population, the characteristics of context and the need to have a narrative to avoid different interpretations of the situation.

**Keywords** Assistive technology · Stigma · Context

## 1 Introduction

Stigma is a broad term that represents a resulting social process of perceptions or experiences related to gender, race, culture, physical deformities or products, where subject or a group is rejected or excluded [1]. This process starts when these characteristics are observed as marks and symbols associated to feelings of shame and not belonging to the society [2].

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Among the product-related stigma are the Assistive Technology (AT) used by people with disabilities, because the perception of decreased function or disability [3]. Products that have a universal design and are obtained at the wish are more attractive and free than those who are obtained by necessity, associated with disorders and disabilities [4].

Parette and Scherer [3] also reports that the stigma associated with the use of AT is related to the expectations of the users and his family, the resulting visibility of the use of AT in public places and perceptions of others, the bystanders. Moreover it can be influenced by the aesthetics of the product, disability acceptance, genre and age of use.

The wheelchair, a device that is a symbol of AT, invokes concepts about the user, like dependency, helplessness, passivity, devaluing the individual and emphasizing their disabilities [1]. The emotional responses of these users should be considered as well as functional possibilities of the wheelchair, so that the feelings associated with stigma is replaced by self-esteem [5].

The context of use, in particular situations in outdoor spaces with people, can increase stigmatization. According to Toney et al. [6], this influence is related to the attention given to the device when used in social situations and the perceived stigma by the obstruction of the AT, in addition to the little desirability of observers to the device.

Moreover, the context also influence the acceptance or rejection of AT. In a study of older people, Gitlin [7] reports that adequate instruction in the context of device usage, maximize the possibility of appropriate use. While Mihailidis and Fernie [8], indicate that the development of systems indicative of specific contexts and adequate situations to each use, increase acceptance of wheelchairs.

The stigma associated with Assistive Technology, like the wheelchair, can influence the User Experience (UX) of the disabled person. According to ISO 9241-210 [9], UX focuses on perception and response resulting from the interaction with a product, during or early of use. This is a consequence of user's internal state (predispositions, expectations, motivations), product characteristics (usability and functionality) and context in which the interaction occurs (work or leisure environments) [10].

Aesthetics is one of the characteristics of the product which can enhance stigma, since the appearance of a product may indicate more or lesser dependency on user. In Assistive Technologies, devices are used daily and can even totally replace a limb or their functions, that gives greater visibility. Dissatisfaction with the aesthetics of these products influences the quality of use and acceptability of the product [11].

Despite the importance of the User Experience of AT, the evaluation of stigma presents difficulties because it related to emotions that are difficult to verbalize. Study developed by Vaes [2], evaluated the behavior by observing the way that people move away where there was users of AT, like hospital masks.

Other stigmatization assessment tools were also developed by Haghighat [12] and King et al. [13], with reference to people with mental health problems, or the disabled person. The questions are related to the perception of the participant on the behavior that other people have to interact with the disabled person and what they think of it. This type of issues do not apply to AT.

The aesthetics of AT as well as the emotional reactions presents when it is observed and used have great impact on stigmatization [2, 3, 14]. In this scope, and based on the fact that the context influences the User Experience with AT Hassenzahl and Tractinsky [10], we are interested in investigating if the context influences the stigmatization of a AT, in particular a traditional wheelchair. For this, we propose a 3D virtual involvement consisting of a garden environment with people, by enabling a situation of experimental control.

# 2 Methodology

## 2.1 Participants

The sample was 46 university students: 14 male and 32 female, of the courses in Ergonomics and Psychomotor Rehabilitation of the Universidade de Lisboa. The age ranged from 18 to 29 years, with a standard deviations of 1.71.

## 2.2 Evaluation Questionnaire

The questionnaire to evaluate the stigma with manual wheelchair was developed using semantic variables related to aesthetic and emotional reactions associated with the UX of the product. The variables related to aesthetics, were collected from researches on specifics scientific books and articles Vaes [2], Parette and Scherer [3], Cowan and Turner-Smith [4], Sapey et al. [5], Gitlin [7] while the emotional variables, were based on emotional semantic of Wheel of Emotions Geneva (Geneva Emotions Wheel) [15]. Those variables were organized in pairs of bipolar adjectives at either end in a Likert scale type of 5 points, chosen because it is easier to understand and use [16].

The aesthetics variables used were: conservative/innovator, complex/simple, uncomfortable/comfortable, insecure/secure and ugly/beauty; while the emotional variables used were: rage/joy, disinterest/interest, sadness/happiness, annoyance/fun, unpleasantness/pleasure, fault/relief, contempt/appreciation, repulsion/acceptance, disappointment/satisfaction, demotivation/motivation, shame/pride and stigma/prestige. O parágrafo anterior não distingue as variáveis relacionadas com a estética e outras relacionais com emoção.

## 2.3 Virtual Environments

The virtual environments was developed based on two requirements to allow assessment of the influence of context on the stigmatization of the wheelchair. One was an environment with a garden with people observing the wheelchair, with good accessibility to exclude the influence of this variable (Fig. 1). In the other environment the wheelchair is alone without any other element in the virtual environment (Fig. 2).

We used the program UNITY 3D (unity3d.com) to develop those virtual environments and create a 40 s film, where a camera circulates around the wheelchair model. Later, the films were integrated in a PowerPoint file with the questions and the semantic differential scale (Fig. 3). Each questions appear seven out of 7 s.

## 2.4 Experimental Protocol

For the evaluation of the influence of context on the stigmatization of the wheelchair were developed two conditions:

**Fig. 1** Wheelchair in an outdoor context

**Fig. 2** Wheelchair without context

| Question number | Response Scale<br>Example: **Ugly** 1 2 3 4 5 **Beauty** |
|---|---|

**Fig. 3** Film image and the Likert scale used

(a) the observation of the wheelchair in an outdoor context accessible, a garden, with evaluation of aesthetics aspects and emotional reactions (Fig. 1).
(b) the viewing the wheelchair alone, for evaluation of the same variables of the previous situation, only in relation to the product (Fig. 2).

Each condition was shown in a room to 23 people, totaling 46 people in the sample. Initially it explained the application of the protocol and the aim of the test, by the following information: during the viewing of the film, watch carefully the video; do not make any comment or sound; answer when asked on paper that was given; respond as soon as possible, because you just have 7 s to answer each question.

After this introduction, an example of the situation with the semantic variables has been shown for each group. It was used an overhead projector and the questions were answered on paper.

## 3 Results

There was identified that the semantical differential with emotional variables presents a tendency for higher average values in garden context, nonetheless we only find statistically significant differences in the demotivation-motivation scale

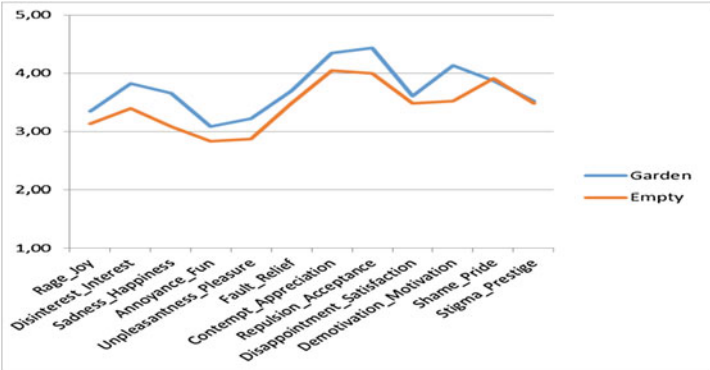


**Fig. 4** Average results for emotional scale

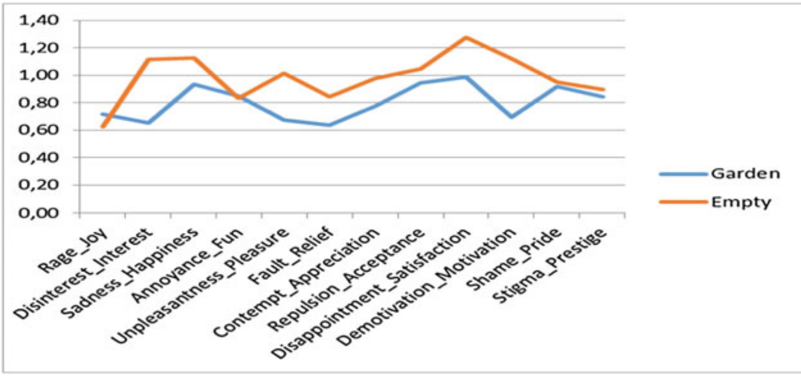


**Fig. 5** Values of standard deviation of emotional scale

(z = −2.018; $p < 0.05$) (Fig. 4). For the same semantical differential, the standard deviation shows a higher variance of results for the empty context (Fig. 5).

In the semantical differential with aesthetics variables there is also a tendency for higher values in the garden context, with an exception for the unsafe-safe scale. However, we only find significant statistical difference for the ugly–beauty scale (z = −2.893; $p < 0.005$) (Fig. 6).

In Fig. 7 are represented values of standard deviation for the aesthetic scale. Unlike in Fig. 5 (SD for emotional scale) there is not a clear tendency for higher variation of results depending on the context.

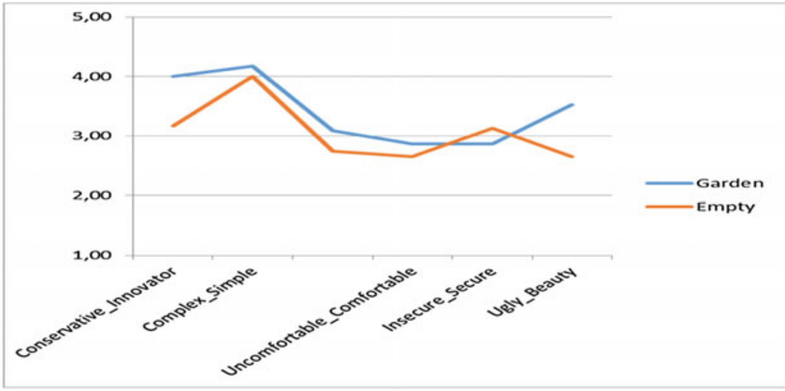


**Fig. 6** Average results for aesthetic scale

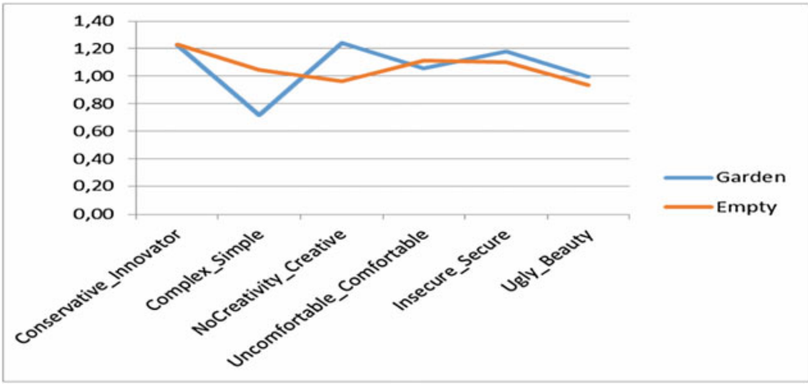


**Fig. 7** Values of standard deviation of aesthetic scale

## 4 Discussion and Conclusion

This paper presents a preliminary study aimed to investigate if the context influences the stigmatization of an AT, in particular a traditional wheelchair.

We don't identified statistically significant differences between the two contexts (garden and empty virtual environments) for the emotional variables, although the situation with garden context presents higher values in the semantic differential. Also, for aesthetics variables, there was not statistically significant differences.

In general, it was not identified stigmatization with the wheelchair by participants (university students), despite the literature Gaffney [1], Parette and Scherer [3], Cowan and Turner-Smith [4], Sapey et al. [5] relate the stigma with AT in external environments. From this, it can be deduced that stigmatization referred in literature, could be associated with other factors such as: the participant population, type of selected context, or the interpretation of the presented situation made by participants. For the participant population, is needed to explore if the opinion of the wheelchair users is the same of a university population or an adult population with lower academic formation. Intercultural studies is also needed to identify differences between different cultures. Related with the context, in this study we used a static virtual environment presented in a movie. For future studies, is needed to explore more complex dynamic virtual environments, for example, where the virtual people interact between them. To be immersive, and put the participants close to the situation, the users can use a head-mounted display and have the opportunity to explore freely the virtual environment before answer the questions.

In this study, we did not identify the reasons for the participant's answers. Considering that the answers are related with the ways that the participants interpret the context, we don't know if the participant's interpretations are connected or not with the context environments. In this context, more studies are needed to verify the need of a narrative, before or during the interaction with de virtual environment, to avoid different interpretations of the situation.

The results of this study showed that there are not statistical differences between the two environments (garden and empty), for a university population and points the need to develop more studies related with the influence of the participant population, the characteristics of context and the need to have a narrative to avoid different interpretations of the situation.

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# The Physical Elements Affecting Student's Concentration in Libraries

**Thao-Hien Dang and Wenzhi Chen**

**Abstract** This study aims to investigate the impact of physical elements in a library's interior design on the concentration of students using the library for their work. The research question is as follows: which physical factors have, from their perspective, an impact on the concentration of students using the library for work? Also, this study compares the importance of the effect of the physical factors on the concentration of different users and activity profiles. There were 24 participants from 3 different Universities located in Guishan, Taoyuan, Taiwan answering the questionnaires and interview questions. Results showed that there were 11 factors rated as the most important factors affecting concentration ability namely: "Cleanliness"; "Aesthetic appearance"; "Noise level"; "Air movement"; "Amount of light"; "Air quality"; "Amount of space"; "Accessibility to facilities"; "Visual comfort"; "Crowdedness"; "Temperature"; and "Comfort of furnishing".

**Keywords** Concentration · Library · Physical elements

## 1 Introduction

For many people, especially students, the library plays an important role in aiding students' advancement in their academic discipline. The library is renowned as a source of information and knowledge and has the same basic objective of offering services to disseminate that knowledge and provide reference materials to users in need [1]. According to the sixteenth public conference of the United Nations Educational, Scientific and Cultural Organization (UNESCO) in 1970, the library is an institution including collections of books, magazines, newspapers, audio-visual

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or graphic materials along with the myriad other services provided by its staff to satisfy users' educational, searching, and informative needs, as well as providing entertainment. In the digital age, a library is not only a physical place for obtaining knowledge, a space for groups to come together or individuals to interact and socialize, it also provides resources through technological devices [2]. Although the traditional function of the academic library as an information retrieval space has become weaker [1], the physical space in a library still has an important role as a student learning area, as many students spend long hours in the library studying and conducting research [3].

The physical factors, in architecture or interior design, are a combination of different elements in a space i.e., lighting, temperature, ventilation systems, size of the room, the floor, the walls, desks, chairs, rugs, whiteboards, computers etc. [4]. Realizing the importance of the library's role in learning, several researchers in the environmental psychology and architectural psychology fields have conducted studies to obtain a clear understanding of the influence of the physical elements in a library on students' behavior and satisfaction. Cha and Kim [5] identified five important factors that influence students' spatial choice in academic libraries: the amount of space; noise level; crowdedness; comfort of furnishing; and cleanliness. Furthermore, daylight and the amount of time spent in the library have significant effects on library users' satisfaction. DeClercq and Cranz [6] discovered that more than half (56 %) of the users preferred to study near a window and preferred not to change seats during study time. Therefore, it is possible to recognize that physical environment factors have a significant impact on library users in general and on students in particular.

In study, the ability to concentrate is an important factor in helping students increase their academic performance. According to Cambridge University, concentration is the ability to directly focus one's thinking in whatever direction one chooses. Scott [7] viewed concentration as the capacity to maintain attention on relevant tasks and ignore irrelevant tasks for the time it takes to complete the task successfully. Concentration can be affected by many factors, including the physical environment. In fact, the influence of lighting on mood (including concentration) was revealed in the study by Hoffmann et al. [8] which compared the effect of different lighting conditions (500–1800 lx; 6500 K; 500 lx; 4000 K) on the mood. Results showed that the concentration index of workers conducting work under variable lighting increased significantly compared to those under regular lighting conditions. Teenagers' attention is particularly sensitive to discomfort conditions [9]. In a classroom with conditions of thermal discomfort, the attention index of a teenager will decline [9]. Another aspect of interior design that designers especially care about is the display of the space because it is likely to have a positive or negative impact on the users. For example, visual environments that are complexly decorated distract children and make them spend more time off-task, and demonstrate lower learning progress in the classroom [10].

This provides useful information about students' choices, behavior, and satisfaction, as well as the relationship between physical elements and the concentration on learning. However, little is known about the impact of the physical factors on students' performance in libraries, especially on their concentration capacity. Thus, this study aims to investigate the impact the physical elements of a library's interior design have on the concentration of students using the library for their work. The research question is as follows: which physical factors have, from their perspective, an impact on the concentration of students using the library for work? Also, this study compares the importance of the physical elements to the concentration of different users with different activity profiles. By understanding the students' perceptions regarding the effect of physical factors on their concentration, designers may be able to create more effective library spaces that significantly improve students' performance.

# 2 Method

## *2.1 Setting*

Libraries at three different universities (Chang Gung University, Chang Gung Technology University and Taiwan National Sport University) located in Guishan, Taoyuan, Taiwan were chosen for this study. The three universities each have different characteristics: Chang Gung University is a research base university with a high number of master and doctoral students and its most popular majors are the sciences, medicine, business management and engineering; the demographic of students at Chang Gung Technology University tend to be younger than at Chang Gung University, and this is a University with a more practical base; finally, Taiwan National Sport University is a sport school with different majors to the other two. In general, the three libraries are used not only as resource centers, but also as social facilities for university students and faculties utilizing their group work areas. The layout designs of the library spaces have many options for all types of work, including group or individual work within open spaces, and some have comfortable furniture. They also have separate computer areas and wireless access areas. All individual study carrels are located near windows, and bookshelves are located in the middle of the spaces for protection from daylight. However, the library at Chang Gung University is in the middle of two buildings: the management building and the engineering building; thus, the first floor of the library connects the two buildings and there is a degree of through-traffic as a result. The other 2 libraries are located in separate buildings and are more isolated from distractions. The research was conducted over two week period during the winter of 2015.

## *2.2 Participants*

The study had 24 participants (12 female and 12 male). There were 8 students in each University participating in the investigation. All of them were students who, at the time of the interview, were studying in one of the libraries, possibly on different floors.

## 2.3 Questionnaire and Interview

The survey included two sections. The first section was divided into Parts A, B and C. Part A requested basic information (personal characteristics: gender, age, grade and frequency of using the library). Part B comprised questions about their current purpose in visiting the library, the important of the physical elements to their concentration ability, their feelings about the environment and their concentration scale at that moment. In Part C of the questionnaire, participants were questioned about the perceived importance of each physical factor regarding concentration ability. In the research by Cha and Kim [5], a list of 18 space attributes was used to discover which attributes influence students' spatial choices in academic libraries. Cha and Kim referenced post-occupancy evaluations (POEs), along with the Center for the Built Environment (CBE), to create the list; their research also considered student behavior in a library (its different characteristic and activities). The physical elements in Cha and Kim's list were found to be relevant and reliable and are suitable for the current research. The survey asked students how important they considered each physical factor was to their concentration ability when they were using the library, measured on a 5 point Likert scale (1 = strongly disagree, 5 = strongly agree). Also some new factors were added following suggestions by the participants.

Section two included 2 interview questions:

1. Could you please explain why you chose these factors as affecting your concentration when you work at the library?
2. Could you please describe your ideal library that would help you work effectively, especially in terms of improving your concentration on your work?

This section aims to discover new elements with the aim of extending the research in future.

## 2.4 Data Analysis

The study analyzed the collected data by using ATLAS ti 5.2. In addition, the scores were compared according to the differences in activities and characteristic of the students using ANOVA.

## 3 Results

Table 1 illustrates the students' profiles with regard to their characteristic and activity information. All of the respondents were less than 25 years old. Under 20 year olds accounted for 45.8 %, and this figure was similar for 21–25 year olds, 54.2 %. Most of them carried a laptop (20.8 %) and visited the library frequently to study (75.0 %) and read (37.5 %). Only a small minority (4.2 %) came to meet others. More than half of the participants came to the library alone. A majority of indicators visited the library on weekdays (83.3 %) and spent between 1 and 5 h (75 %) there. In terms of the time, students in the survey preferred to stay at the library in the morning, afternoon and evening (37.4, 70.8, 45.8 %, respectively). Regarding visit frequency, a significant proportion of participants claimed that they visited the library weekly (45.8 %). In addition, 50 % of the students considered the physical elements to be important to their concentration, with a mean score of nearly 4. Finally, nearly 58.3 % of students gave a score of 4 for their concentration scale (a mean score of around 4).

Table 2 revealed the difference in the important of physical elements and concentration scale according to students' personal and activities profile. The result showed that there is no difference founded ($p > 0.05$).

Table 3 indicates the overall perceived importance of the physical elements in the library to the concentration ability of the students. The first 11 elements had mean scores higher than 4 and were considered the most important, beginning with the highest: "Cleanliness"; "Aesthetic appearance"; "Noise level"; "Air movement"; "Amount of light"; "Air quality"; "Amount of space"; "Accessibility to facilities"; "Visual comfort"; "Crowdedness"; "Temperature"; "Comfort of furnishing". For indicators, some attributes related to the natural elements such as "Natural light", "Window view", "Natural elements insides library" were less important with mean scores lower than 4 from the students' perception. Moreover, some factors attributed to indoor quality, namely "Adjustability of furniture", "Distance from an entrance", "Ease of interaction with friends" were also not determinants.

Table 4 shows the correlation between the physical elements and their importance as well as the concentration scale. Results show that there was a positively significant correlation between the concentration scale and "Visual privacy". Also, according to Table 4, participants concerned about the important of the physical determinants also paid more attention to "Cleanliness", "Temperature", "Amount of light", "Visual comfort", "Noise level", and "Sound privacy" ($p < 0.05$).

Table 5 presents the results of the ANOVA conducted between the subgroups distributed respectively by activity information and users' characteristics. A gender difference was found in "Noise Level" ($F = 5.966$, $p = 0.023$), with males being more concerned about this factor than females. Besides which, age was found to influence the rating of "Adjustability of furniture" ($F = 4.333$, $p = 0.049$).

**Table 1** Participants' profile

| Item | Sub-item | N | % |
|---|---|---|---|
| Age | Under 20 | 11 | 45.8 |
| | 21–25 | 13 | 54.2 |
| Grade | Undergraduate | 23 | 95.8 |
| | Graduate | 1 | 4.2 |
| Visit frequency | First time | 2 | 8.3 |
| | Everyday | 5 | 20.8 |
| | Weekly | 11 | 45.8 |
| | Every 2 weeks | 2 | 8.3 |
| | Every 3 weeks | 1 | 4.2 |
| | Monthly | 1 | 4.2 |
| | Rarely | 4 | 16.7 |
| Amount of time | Under 1 h | 1 | 4.2 |
| | 1–3 h | 9 | 37.5 |
| | 3–5 h | 9 | 37.5 |
| | 5–7 h | 4 | 16.7 |
| | Over 7 h | 1 | 4.2 |
| Day | Weekday | 20 | 83.3 |
| | Weekend | 8 | 33.3 |
| Time | Morning | 9 | 37.4 |
| | Afternoon | 17 | 70.8 |
| | Evening | 11 | 45.8 |
| | Night | 6 | 25.0 |
| Activates | Reading | 9 | 37.5 |
| | Working | 18 | 75.0 |
| | Meeting | 1 | 4.2 |
| | Using laptop | 5 | 20.8 |
| | Using computer | 2 | 8.3 |
| With friends | Yes | 5 | 20.8 |
| | No | 19 | 79.2 |
| Importance of physical elements | 1 Not important | 1 | 4.2 |
| | 2 Slightly important | 3 | 12.5 |
| | 3 Moderately important | 6 | 25.0 |
| | 4 Important | 12 | 50.0 |
| | 5 Very important | 2 | 8.3 |
| Concentration scale | 1 | 0 | 0.0 |
| | 2 | 1 | 4.2 |
| | 3 | 4 | 16.7 |
| | 4 | 14 | 58.3 |
| | 5 | 5 | 20.8 |

**Table 2** The difference in the important of physical elements and concentration scale according to students' personal and activities profiles

| | Important of physical elements | | Concentration scale | |
|---|---|---|---|---|
| Item | F | p | F | p |
| Gender | 2.255 | 0.147 | 0.071 | 0.792 |
| Age | 3.139 | 0.090 | 0.699 | 0.412 |
| Grade | 0.311 | 0.583 | 0.003 | 0.956 |
| Visit frequency | 0.403 | 0.840 | 0.426 | 0.824 |
| Amount of time | 0.684 | 0.612 | 2.110 | 0.119 |
| With friends | 0.764 | 0.391 | 0.019 | 0.893 |

**Table 3** The importance of physical elements

| Category | Item | N | Mean | Std. deviation |
|---|---|---|---|---|
| Space allocation | Accessibility to facilities | 24 | 4.21 | 0.509 |
| | Amount of space | 24 | 4.21 | 0.588 |
| | Crowdedness | 24 | 4.12 | 0.850 |
| | Distance from an entrance | 24 | 3.63 | 0.711 |
| | Ease of interaction with friends | 24 | 3.63 | 0.647 |
| | Visual privacy | 24 | 3.96 | 0.806 |
| | Window view | 24 | 3.71 | 0.859 |
| | Natural elements inside library | 24 | 3.46 | 0.721 |
| Furniture | Adjustability of furniture | 24 | 3.67 | 0.702 |
| | Comfort of furnishing | 24 | 4.04 | 0.550 |
| Atmosphere and cleanliness | Aesthetic appearance | 24 | 4.38 | 0.711 |
| | Cleanliness | 24 | 4.54 | 0.721 |
| Temperature | Temperature | 24 | 4.04 | 0.859 |
| | Air movement | 24 | 4.25 | 0.676 |
| Air quality | Air quality | 24 | 4.21 | 0.721 |
| Lighting | Amount of light | 24 | 4.21 | 0.779 |
| | Visual comfort (glare, reflection, contrast) | 24 | 4.17 | 0.868 |
| | Natural light (from windows, doors) | 24 | 3.67 | 0.963 |
| Hearing quality | Noise level | 24 | 4.25 | 0.737 |
| | Sound privacy | 24 | 3.92 | 0.929 |

Respondents in the 21–25 age group had higher scores on these factors than the respondents who 20 or younger. Whether this was their first time visit or not also impacted students in terms of the "Air movement" factor (F = 7.496, $p = 0.012$). Indeed, the "Air movement" factor was generally affected by the frequency of

**Table 4** Correlation between the physical elements, importance of physical elements, and concentration scale

| Physical factors | Important of physical elements | | Concentration scale | |
|---|---|---|---|---|
| Visual privacy | | | 0.356 | * |
| Cleanliness | 0.373 | * | | |
| Temperature | 0.598 | ** | | |
| Amount of light | 0.383 | * | | |
| Visual comfort | 0.470 | * | | |
| Noise level | 0.498 | ** | | |
| Sound privacy | 0.475 | ** | | |

*$p < 0.05$, **$p < 0.01$

visiting (F = 3.365, $p = 0.025$), with students coming to libraries once every 2 weeks highly valuing "Air movement". Frequency of visitation significantly affected reactions to "Comfort of furnishing" (F = 3.204, $p = 0.030$) with participants visiting libraries once every 2 weeks less valuing "Comfort of furnishing" compared to who went there weekly and every day. In addition, people spending less time at the library (1–3 h) thought "Visual privacy" more important to their concentration ability (F = 2.978, $p = 0.046$).

Table 6 shows the various different scores for the students' evaluations of the importance of the physical factors to their concentration capacity, according to their personal information and activity profile. There was a difference between students who visited the library in the morning and those who didn't. This finding indicates that the "Amount of space", "Air movement", "Air quality", and "Noise level" factors were more higher valued by students who did not use the library in the morning. Night time usage also made a difference to perceptions of the "Temperature" factor, which is reasonable given that students using the library at night are more likely to be concerned about this factor. Finally, while participants thought "Accessibility to facilities", "Visual privacy", "Comfort of furnishing", and "Visual comfort" were important for concentration while using a computer, in contrast, participants who did not go to the library to use a computer highly valued "Window view" and "Natural elements inside".

Finally, regarding the interview, there were not many new elements found. According to the answers, almost of the reasons or factors were listed in the questionnaire and found in the literature. However, interestingly, the interview results showed that participants were concerned with relatively trivial details such as "the sound of someone bumping into the desk", "the sound of sneezing", or "the sound of books". Besides which, almost all of them required a privacy space for reading which could not be disturbed by the surrounding environment.

**Table 5** The results of ANOVA on importance of physical elements by gender, age, degree, visiting frequency, sitting time, and whether with friends

| Item | Gen | | Age | | Deg | | Fre | | Tim | | Fri | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | F | *p* | F | *p* | F | *p* | F | *p* | F | *p* | F | *p* |
| Accessibility to facilities | 0.155 | 0.698 | 1.085 | 0.309 | 0.169 | 0.685 | 1.068 | 0.410 | 0.344 | 0.845 | 0.891 | 0.355 |
| Amount of space | 1.088 | 0.308 | 0.802 | 0.380 | 0.126 | 0.726 | 0.229 | 0.945 | 0.253 | 0.904 | 0.001 | 0.973 |
| Crowdedness | 0.508 | 0.484 | 0.031 | 0.861 | 0.022 | 0.885 | 2.399 | 0.078 | 1.430 | 0.262 | 2.573 | 0.123 |
| Distance from an entrance | 0.079 | 0.781 | 0.409 | 0.529 | 0.799 | 0.381 | 0.414 | 0.833 | 0.495 | 0.740 | 0.372 | 0.548 |
| Ease of interaction with friends | 0.096 | 0.760 | 0.298 | 0.591 | 0.973 | 0.335 | 0.512 | 0.764 | 0.664 | 0.625 | 2.236 | 0.149 |
| Visual privacy | 0.566 | 0.460 | 0.073 | 0.790 | 1.506 | 0.233 | 1.216 | 0.342 | 2.978 | 0.046 | 1.975 | 0.174 |
| Window view | 0.054 | 0.818 | 0.009 | 0.923 | 2.517 | 0.127 | 0.079 | 0.995 | 0.827 | 0.524 | 0.097 | 0.759 |
| Natural elements inside library | 0.712 | 0.408 | 0.340 | 0.566 | 5.756 | 0.025 | 0.561 | 0.728 | 2.089 | 0.122 | 0.804 | 0.380 |
| Adjustability of furniture | 3.356 | 0.081 | 4.333 | 0.049 | 0.227 | 0.638 | 1.446 | 0.256 | 1.250 | 0.324 | 0.908 | 0.351 |
| Comfort of furnishing | 1.253 | 0.275 | 0.112 | 0.741 | 0.006 | 0.940 | 3.204 | 0.030 | 1.613 | 0.212 | 0.512 | 0.482 |
| Aesthetic appearance | 0.079 | 0.781 | 0.005 | 0.944 | 0.799 | 0.381 | 0.549 | 0.737 | 0.652 | 0.633 | 0.372 | 0.548 |
| Cleanliness | 0.077 | 0.784 | 1.251 | 0.275 | 0.411 | 0.528 | 0.252 | 0.934 | 0.631 | 0.646 | 0.040 | 0.844 |
| Temperature | 0.054 | 0.018 | 1.400 | 0.249 | 1.318 | 0.263 | 0.978 | 0.458 | 2.648 | 0.065 | 0.489 | 0.492 |
| Air movement | 0.000 | 1.000 | 1.132 | 0.299 | 1.303 | 0.266 | 3.365 | 0.025 | 1.099 | 0.386 | 7.496 | 0.012 |
| Air quality | 0.077 | 0.784 | 1.751 | 0.199 | 1.273 | 0.271 | 2.656 | 0.057 | 1.010 | 0.427 | 2.124 | 0.159 |
| Amount of light | 0.066 | 0.800 | 1.483 | 0.236 | 0.072 | 0.791 | 0.516 | 0.761 | 0.531 | 0.715 | 1.641 | 0.214 |
| Visual comfort | 0.000 | 1.000 | 3.649 | 0.069 | 0.037 | 0.850 | 0.431 | 0.821 | 0.062 | 0.992 | 0.445 | 0.512 |
| Natural light | 1.664 | 0.210 | 1.304 | 0.266 | 2.095 | 0.162 | 1.715 | 0.182 | 1.300 | 0.306 | 0.748 | 0.396 |
| Noise level | 5.966 | 0.023 | 2.486 | 0.129 | 1.084 | 0.309 | 1.173 | 0.360 | 0.388 | 0.814 | 0.028 | 0.869 |
| Sound privacy | 0.000 | 1.000 | 1.925 | 0.179 | 0.008 | 0.929 | 1.324 | 0.298 | 1.577 | 0.221 | 0.096 | 0.760 |

*Gen* gender, *Age* age, *Deg* degree, *Fre* frequency, *Tim* time, *Fri* friends; $*p < 0.05$)

**Table 6** The difference in mean of physical elements according to the different times and activities

| | Morning | | Night | | Using computer | |
|---|---|---|---|---|---|---|
| Physical factors | Yes | No | Yes | No | Yes | No |
| Amount of space | 4.00 | 4.56 | | | | |
| Air movement | 4.07 | 4.56 | | | | |
| Air quality | 4.00 | 4.56 | | | | |
| Noise level | 4.00 | 4.67 | | | | |
| Temperature | | | 3.78 | 4.83 | | |
| Accessibility to facilities | | | | | 5.00 | 4.14 |
| Visual privacy | | | | | 5.00 | 3.86 |
| Window view | | | | | 2.50 | 3.82 |
| Natural elements inside library | | | | | 2.50 | 3.55 |
| Comfort of furnishing | | | | | 5.00 | 3.86 |
| Visual comfort (glare, reflection, contrast) | | | | | 5.00 | 4.09 |

## 4 Discussion

Compared to other research, the current study found both similarities and differences. First, Cha and Kim [5] identified the five most important factors impacting the spatial choices of students in a library as being: "Amount of space"; "Noise level"; "Crowdedness"; "Comfort of furnishing"; and "Cleanliness". For the current study, participants also cited these five factors as being the most important regarding concentration ability when they were working. However, "Aesthetic appearance", "Air movement", "Amount of light", "Accessibility to facilities", and "Temperature" were the most commonly cited factors in this research: in the Cha and Kim [5] study, these elements were not highly rated by students. Furthermore, in both studies, "Window view" was rated as one of the least influential factors, which lies in contrast to some former studies where researchers believed that outdoor views attracted students and that they preferred seats closer to a window [5]. This suggests that the attractiveness of a space near a window is more closely related to the presence of natural light rather than the window view. Students' preference for natural light has been proven in many studies [11]. However, in this study, "Natural light" was not highly rated within the list. Students' preference for seats near a window may also be because the view helps reduce stress, and this might relate to concentration: this issue requires further investigation. It is interesting that "Aesthetic appearance" was chosen as the one of the most important elements. Student perception might connect, "Aesthetic appearance" to the scholarly atmosphere formed by the many design elements; thus, this matter also needs to be investigated further by future research.

The results showed no difference in the concentration scale between the many groups. Nonetheless, Mazon [9] discovered disparities in the concentration index according to gender and age. For instance, the findings revealed that teenage attention at ages 17 and 18 showed little difference in discomfort in respect to thermally comfortable conditions; however, when compared with the 12–14 age group, the attention index decreases around 50 % with respect to comfort conditions. Another difference is that "Natural elements" and "Natural light" were rated as having some of the lowest effects. This contrasts with the research by Sulaiman et al. [4] which argued that students studying outside will concentrate more and gain higher achievement. Clearly, this matter needs further research in future in order to clarify the issue.

This study also discovered that the importance of the physical elements to concentration varied according to the different user and activity profiles. Therefore, these findings on the varying importance of space attributes indifferent contexts may provide architects with fundamental information on user-driven design in terms of space usage, and may allow them to employ diverse pace use patterns according to different users and activities. For example, the results indicate that male students value "Noise level" more than female students do: thus if some space in a library is intended to accommodate more male than female students, architects should focus more on "Noise level" in designing and planning that space than for other spaces in the library.

## 5 Concluding Remarks

To create an effective design for a learning space, it is important to understand the impact of the interior physical environment on users' perceptions. This study investigated the students' perceptions of the influence of physical elements on their concentration ability. The results showed that 11 factors: "Cleanliness"; "Aesthetic appearance"; "Noise level"; "Air movement"; "Amount of light"; "Air quality"; "Amount of space"; "Accessibility to facilities"; "Visual comfort"; "Crowdedness"; "Temperature"; and "Comfort of furnishing" were the highest ranked in the list. Besides which, when students were asked about their ideal library, most of them claimed that they needed more private spaces and bigger tables in order to be able to study effectively.

Some limitations of the study may affect the generalizations in the results. Firstly, the research only involved a relatively small sampling of participants; hence, the results might not be reliable enough to generalize. Secondly, the research was conducted during the winter months, and the cold weather could therefore have influenced the "Temperature" elements in the research. Finally, although the study was conducted at three different Universities, the three Universities are located close to each other, resulting in a lack of diversity in the geographical conditions. To deal with these limitations, a greater body of research should be conducted involving many different locations as well as a higher number of participants.

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# Part V
# Ergonomics in Clothing and Footwear Design

# Effects of Different Body Postures on Anthropometric Measures

**Sara Bragança, Pedro Arezes, Miguel Carvalho and Susan Ashdown**

**Abstract** The shape and size of the human body is affected by the posture adopted in order to perform various activities. The human body is constantly changing and adapting to the movements executed in everyday life. As such, knowledge about the body changes that occur with the adoption of different postures is essential. Besides the obvious adverse health effects caused by spending long periods of time in certain postures, the adopted posture may influence people's interaction even with the simplest items such as clothing. For all these reasons, being able to determine the anthropometric changes related to different work postures is very important to occupational ergonomics. The main objective of this paper is to identify and quantify the body changes that occur with each of the postures adopted.

**Keywords** Anthropometry · Working postures · Human body · Variations

## 1 Introduction

Fashion designers have to rely on anthropometric studies that represent target populations, considering their standing and static position. However, it can be difficult to find appropriate anthropometric data and the most frequent situation is to have anthropometric data that has been collected from populations that are

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noticeably different from the target populations [1]. In many countries the products are designed according to the extensive data available for military populations.

Unlike other consumer products, with dimensions based on combined anthropometric data from men and women, data needed for clothing design is very sensitive.

Body shapes and sizes vary according to many factors as gender, age and culture in ways that have an impact on clothing fit.

Additionally, anthropometric surveys are usually different in terms of population size, age groups, procedures used and, time of the measurements [2]. All these aspects can lead to a mismatch in the dimensions of the product and the user.

Some researchers have tried to determine the changes in shape and size of the human body that occur according to the posture adopted. For example, Carvalho et al. [3] performed a comparative anatomical study between the standing and sitting positions, analyzing the dimensional and postural alterations of the human body when sitting, in which they identified:

- Shrinkage of the trunk;
- Volume increase in the abdominal region;
- Variation in height, volume and inclination of the waist;
- Broadening of the hips;
- Redistribution of the muscular mass in the thighs;
- Increase of upper-back bending;
- Modification of the angular position of the elbow;
- Increase of the leg frontal length caused by the flexion of the knees.

Most of these postures can become uncomfortable for workers, especially when the clothes they wear are not adequate and cannot be adapted to the challenges of the tasks to be performed. As such, some of these challenges can be mitigated when wearing appropriate clothing, preventing health issues and increasing perceived comfort.

Frequently some discomfort in clothing can be felt with movement or when dynamic postures are assumed. When the body moves the dimensions change, for example the increase of the length on one side of a bending joint and the decrease of the length on the other side [4]. If the clothing does not increase in dimension over a bending joint, or binds where body dimensions decrease, it will restrict movement or intensify its difficulty creating discomfort.

Several studies evaluated the impact of the body changes in the clothing fit and comfort. Lotens [5] determined the ease needed in clothing for seven extreme postures. Cichocka et al. [6] quantified body changes with movement for the shoulders, buttocks, arms, legs, elbows and knees. Aldrich et al. [7] described garment distortions related to body movements. Lee and Ashdown compared [8] the variations in upper body measurements for three active postures. Choi and Ashdown [9, 10] calculated the differences in body measurements between standing and sitting postures, finding an increase of waist girth by 8 %; an increase of hip girth by 7 %; a decrease of crotch girth by 16 % and an increase of center leg length by 10 % when in the sitting posture.

According to Cichocka et al. [11] developing a garment may be one of the most difficult problems in the field of textile engineering, and consequently, before designing a garment adapted to the human body, it is imperative to have an intimate knowledge of its morphology in order to create the final style successfully.

In this paper the anthropometric measurements of 50 workers were collected in different postures. The purpose of this was to quantify the variations that occur in the human body when different postures are adopted. Moreover, it allowed understanding how this variability will affect the clothing design in order to maximize fit and comfort.

## 2 Materials and Methods

Fifty participants volunteered to take part in this study; 12 of them were females and 38 were males. This sample had an average age of 36.49 ± 11.39 years old, an average height of 170.86 ± 69.3 cm and an average weight of 71.30 ± 10.70 kg.

The participants worked in four different companies/institutions—one research centre, one software development company, one industrial company and one university. A formal contact was established with the companies, inviting them to participate in the study. The participation in this study was voluntary and the management board of the company selected the participants. When contacted, the participants were informed of the detailed procedures and requirements of the test.

The data collection was performed by one certified anthropometrist that collected all the anthropometric data, using traditional anthropometry techniques (with a regular measuring tape and a Harpenden anthropometer). A total of 25 measurements were collected, representing the basic body measurements that are needed for the design of the base patterns [12]. Some of the measurements were collected in different postures to try to identify the modifications on the body that occur when people are not on the stationary standing position. These postures were selected to include postures where more significant differences were expected to be found and, as shown in Fig. 1, were the following:

- P1: stationary standing with arms to the sides;
- P2: sitting with the knees bent at 90° and feet touching the ground;
- P3: standing with arms to the front parallel to the ground;
- P4: standing with arms up in a 180-degree angle with the trunk;
- P5: standing with arms to the sides in a 90-degree angle with the trunk.

The anthropometric measurements collected were divided in two categories: static (the ones collected in posture P1 and posture P2) and dynamic (the ones collected in the other postures, P3, P4 and P5)—Table 1.

Figure 2 shows a representation of the measurements in the human body.

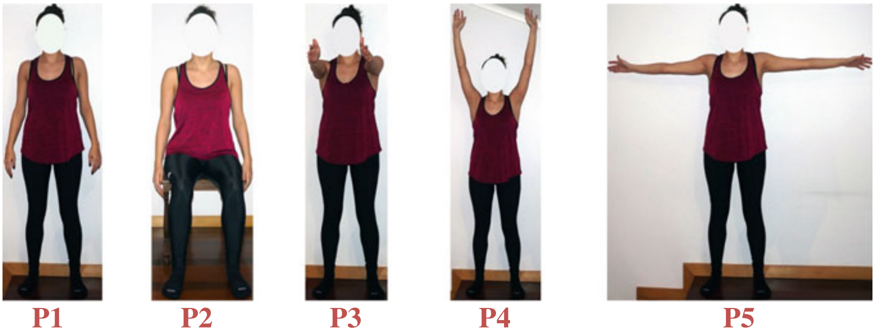


**Fig. 1** Postures in which the measurements were taken (from P1 to P5)

**Table 1** Measurements collected for the study

| Type | ID | Measurement | Posture | Type | ID | Measurement | Posture |
|---|---|---|---|---|---|---|---|
| Static | 1 | Neck base girth | P1 | Dynamic | 18 | Waist girth | P1, P2 |
| | 2 | Chest girth | P1 | | 19 | Abdomen girth | P1, P2 |
| | 3 | Knee girth | P1 | | 20 | Hip girth | P1, P2 |
| | 4 | Calf girth | P1 | | 21 | Thigh girth | P1, P2 |
| | 5 | Ankle girth | P1 | | 22 | Leg length | P1, P2 |
| | 6 | Arm girth | P1 | | 23 | Crotch length | P1, P2 |
| | 7 | Forearm girth | P1 | | 24 | Across chest length | P1, P3, P4, P5 |
| | 8 | Arm length | P1 | | 25 | Across back length | P1, P3, P4, P5 |
| | 9 | Crotch length back | P2 | | | | |
| | 10 | Crotch length front | P2 | | | | |
| | 11 | Upper leg length | P2 | | | | |
| | 12 | Lower leg length | P1 | | | | |
| | 13 | Knee height | P1 | | | | |
| | 14 | Waist height | P1 | | | | |
| | 15 | Shoulder height | P1 | | | | |
| | 16 | Stature | P1 | | | | |
| | 17 | Weight | P1 | | | | |

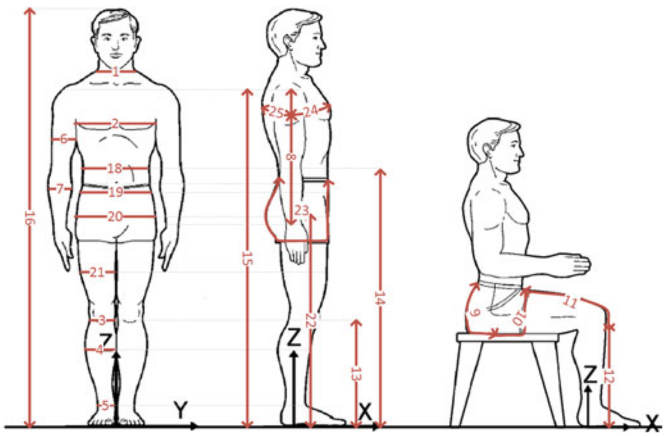

**Fig. 2** Representation of the measurements taken on the human body

Regarding the analysis of the data, descriptive statistics were calculated (mean and standard deviation), as well as the mean differences registered between the measurements collected in the static and in the dynamic postures. To analyze the meaning of these differences, a paired samples t-test was used. The significance level was set at 0.05 ($\alpha = 0.05$), meaning that body measurements with $p$ values lower than 0.05 were considered to have significant difference between postures.

## 3 Results and Discussion

Table 2 shows the means, standard deviations, minimum and maximum values for all measurements collected with all the 50 participants.

The results obtained demonstrate that there is a difference in the measurements according to the posture adopted. Table 3 displays the mean difference registered (both in mm as in percentage) when the posture changes. Positive values imply that the body measurement increases from P1 to the other posture (P2, P3, P4 or P5) while negative values indicate that the body measurement decreases with the posture.

As it can be seen, there are some measurements with considerable differences according to the posture adopted. For example, raising the arms upwards makes the across chest length decrease about 16 %, when compared to the regular static standing posture. As all the body measurements are related to one another, consequently, the across back length increases about 5 %.

Most of the measurements had a large variation. However, there are other measurements that only change slightly, as is the case of the leg length, which only increases about 1 %.

**Table 2** Mean, standard deviation, minimum and maximum values of the body measurements considered (in mm)

| Measurement | Mean | Standard deviation | Maximum | Minimum |
|---|---|---|---|---|
| Neck base girth | 396.2 | 25.2 | 457.0 | 338.9 |
| Chest girth | 994.4 | 86.2 | 1317.1 | 820.5 |
| Knee girth | 359.7 | 24.2 | 432.4 | 307.5 |
| Calf girth | 368.5 | 26.3 | 444.5 | 323.0 |
| Ankle girth | 243.3 | 24.1 | 331.6 | 210.0 |
| Arm girth | 306.1 | 34.4 | 397.0 | 230.0 |
| Forearm girth | 253.0 | 32.3 | 350.0 | 182.6 |
| Arm length | 541.4 | 38.2 | 650.0 | 473.5 |
| Crotch length back | 422.9 | 78.7 | 550.0 | 347.4 |
| Crotch length front | 250.5 | 59.5 | 395.0 | 202.6 |
| Upper leg length | 460.4 | 40.2 | 555.0 | 390.0 |
| Lower leg length | 431.8 | 90.1 | 550.0 | 250.0 |
| Knee height | 539.9 | 122.3 | 744.0 | 291.8 |
| Waist height | 1168.3 | 364.5 | 3610.0 | 957.2 |
| Shoulder height | 1415.6 | 87.5 | 1593.0 | 1248.7 |
| Stature | 1708.6 | 69.3 | 1830.0 | 1560.0 |
| Weight | 713.0 | 107.0 | 1003.0 | 518.0 |
| Waist girth P1 | 831.5 | 94.3 | 1087.0 | 678.0 |
| Waist girth P2 | 864.9 | 100.3 | 1161.0 | 706.0 |
| Abdomen girth P1 | 918.3 | 99.6 | 1194.8 | 762.0 |
| Abdomen girth P2 | 984.8 | 136.9 | 1331.2 | 765.0 |
| Hip girth P1 | 982.5 | 65.1 | 1169.0 | 856.0 |
| Hip girth P2 | 1020.2 | 66.6 | 1232.0 | 907.0 |
| Thigh girth P1 | 488.3 | 41.4 | 607.0 | 430.0 |
| Thigh girth P2 | 507.3 | 44.9 | 605.0 | 405.0 |
| Leg length P1 | 891.3 | 117.2 | 1075.0 | 670.0 |
| Leg length P2 | 894.4 | 87.8 | 1040.0 | 740.0 |
| Crotch length P1 | 708.6 | 91.3 | 930.0 | 530.0 |
| Crotch length P2 | 668.5 | 129.9 | 880.0 | 500.0 |
| Across chest length P1 | 443.8 | 55.4 | 553.0 | 348.0 |
| Across chest length P3 | 393.8 | 60.5 | 516.0 | 292.0 |
| Across chest length P4 | 379.6 | 60.0 | 503.0 | 295.0 |
| Across chest length P5 | 424.6 | 55.0 | 528.0 | 315.0 |
| Across back length P1 | 503.4 | 55.5 | 600.0 | 369.0 |
| Across back length P3 | 533.3 | 70.7 | 750.0 | 380.0 |
| Across back length P4 | 528.2 | 70.1 | 660.0 | 338.0 |
| Across back length P5 | 497.6 | 55.5 | 590.0 | 373.0 |

**Table 3** Mean differences between body measurements in different postures

| Measurement | Mean difference in mm (and percentage %) | | |
|---|---|---|---|
| Waist girth | +33.4 (+4.04 %)[a] | | |
| Abdominal girth | +63.9 (+6.96 %)[a] | | |
| Hip girth | +37.7 (+3.86 %)[a] | | |
| Thigh girth | +19.0 (+4.05 %)[a] | | |
| Leg length | +39.2 (+0.86 %)[a] | | |
| Crotch length | −26.5 (−5.57 %)[a] | | |
| Across chest length | −50.1 (−11.37 %)[b] | −64.2 (−15.83 %)[c] | −19.2 (−4.17 %)[d] |
| Across back length | 30.0 (+5.91 %)[b] | 24.8 (+4.82 %)[c] | −5.8 (−1.09 %)[d] |

[a]P1 compared to P2
[b]P3 compared to P1
[c]P4 compared to P1
[d]P5 compared to P1

**Table 4** Results of the paired-samples t-test

| Measurement | | t | df | Sig. (2-tailed) |
|---|---|---|---|---|
| Pair 1 | Waist girth P1—waist girth P2 | −9.643 | 49 | <0.001* |
| Pair 2 | Abdomen girth P1—abdomen girth P2 | −9.088 | 47 | <0.001* |
| Pair 3 | Hip girth P1—hip girth P2 | −14.481 | 49 | <0.001* |
| Pair 4 | Thigh girth P1—thigh girth P2 | −4.307 | 49 | <0.001* |
| Pair 5 | Leg length P1—leg length P2 | −0.496 | 49 | 0.622** |
| Pair 6 | Crotch length P1—crotch length P2 | 2.761 | 49 | 0.008** |
| Pair 7 | Chest P1—chest P3 | 12.404 | 49 | <0.001* |
| Pair 8 | Chest P1—chest P4 | 9.452 | 49 | <0.001* |
| Pair 9 | Chest P1—chest P5 | 4.774 | 49 | <0.001* |
| Pair 10 | Back P1—back P3 | −5.677 | 49 | <0.001* |
| Pair 11 | Back P1—back p4 | −5.229 | 49 | <0.001* |
| Pair 12 | Back P1—back P5 | 2.130 | 49 | 0.038** |

*$p < 0.05$ statistically significant difference; **$p > 0.05$ no statistically significant difference

The results of the paired samples t-test (shown in Table 4) demonstrated that for the majority of the comparisons there is a statistically significant difference ($p < 0.05$) between the measurements.

Amongst all the pairs, the only ones that did not have a statistically significant difference were the leg length, the crotch length and the across back length in P1 and P5. However, it should be noted that the crotch length pair showed a value very close to 0.05. This means that if the significance level was set at a higher value (e.g. 0.09 rather than 0.05) the difference between this pair of measurements would be considered to have a statistically significant difference.

A previous study, conducted by the authors to the same sample by applying questionnaires, revealed to be in accordance with the data obtained from the anthropometric measurements [13]. The areas pointed-out as areas of limitation of movements in the questionnaire were the ones measured in the study in distinct postures—sleeves; armholes; shoulders; chest and back, evaluated through the across chest length and across back length; waist evaluated through the waist girth; hip evaluated through the hip girth; thighs evaluated through the thigh girth; legs evaluated through the leg length. Additionally, all these areas presented a considerable variation with the change in the posture adopted. These changes are even visible to the naked eye, as demonstrated in Figs. 3 and 4, where it is clear that when the posture changes the body shape and size varies accordingly.

From standing to sitting, i.e., from P1 to P2, the variations occur mostly in the lower part of the body. These variations include: (i) the increase in the breadth of the hip and thighs due to the pressure exerted by the stool; (ii) the reduction in the spinal column's arch due to the rotation of the hip forewords; (iii) the augmentation of the protuberance in the abdominal region; and (iv) the increase in the leg length in the front of the leg over the knee caused by the bending of the knees.

When changing from P1 to P3 the variations occur solely in the upper part of the body. Some of these variations include: (i) the increase in the shoulder height;

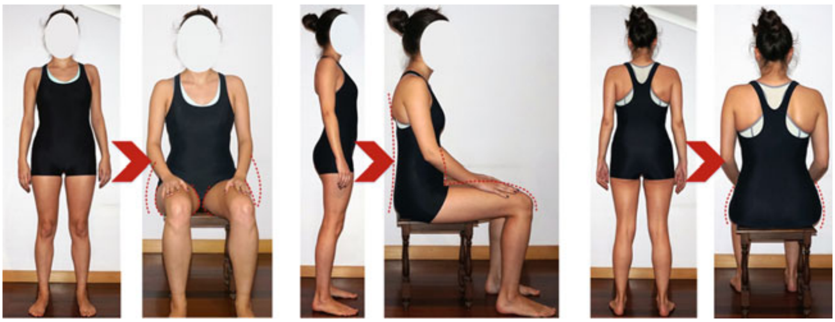

**Fig. 3** Changes in the body that occur from standing to sitting

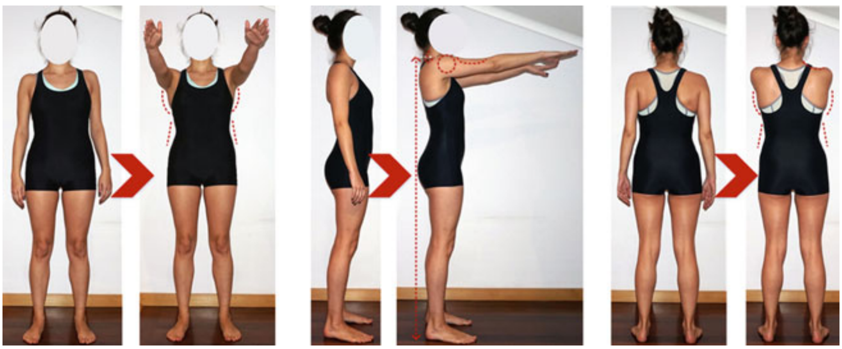

**Fig. 4** Changes in the body that occur from P1 to P3

(ii) the reduction of the waist curvature (more evident in women); (iii) the decrease in the chest breadth; (iv) the intensification of tension in the shoulders and arms regions (especially in the deltoid, biceps and trapezius muscles); and (v) the increase in the back breadth.

In fact, all the measurements in this study, except the leg length, presented a statically significant difference when the posture changes. This makes it easy to understand that the feeling of comfort with clothing that users get is not the same when they are in different dynamic postures. Despite the variation in the measurements was almost all below 10 %, it is still a considerable difference that may have a great impact on garment fit and comfort.

## 4 Conclusions

People are becoming more and more sedentary but there is still the need to perform some movements and adopt some postures during leisure and work activities that may be negatively influenced by clothing. Some examples of those types of postures are the ones presented in this study, which proved to have quite a meaningful impact on the anthropometric measurements and consequent fit and comfort of clothing items.

The significance of the differences quantified here can also be demonstrated with other test (e.g. measurement of compression forces exerted by clothing when in different postures), where it would be possible to see that clothes that are not designed taking in consideration the dynamic postures affect in great part the compression imposed to the user, limiting his/her movements and causing discomfort.

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# A Research on Ergonomic Approaches of Apparel Designers

**Emine Koca and Özlem Kaya**

**Abstract** In today's market environment where customer needs and wants change constantly, only designing products with technical excellence is not enough for the success of the firm. Ergonomic characteristics to meet the expectations of the customers like physical, psychological and affective comfort started to stand out in all kinds of products. In this regard, in terms of apparel ergonomics, it is important that apparel designers who are active in apparel production have ergonomic point of view. In this study in where it is aimed to evaluate ergonomic approaches of designers during the apparel designing process; assessment means which was prepared by researchers was applied to 135 designers who work in ready made garment industry in 2015 and operate in Istanbul, Bursa, Ankara and Corum cities. By analyzing the obtained data statistically, designers' ergonomic approaches toward apparel design were evaluated and some suggestions were offered.

**Keywords** Ergonomy · Design · Apparel comfort · Ready made apparel

## 1 Introduction

History and development of textile and clothing industry in the world is based on a long standing background. Textile products have led to the development of international trade relations and have shaped the economic activities between the east and west from past to modern times. The attire which has come about from the necessity has become an industry with the increase of production and product range during the industrialization process [1].

In textile and clothing industry as for the design which provide important added value in terms of competition encompasses to design new products by taking into

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account the criterions like aesthetics, functionality, ergonomics, material knowledge, marketability, production methods which address the need and problems of consumers for mainly mass production [2].

Design is an innovative process and but nonetheless it doesn't occupy the vast space where the colours, shapes and materials are chosen completely free. Each design object come into being at the end of development process which is affected by various states and decisions that aren't only artistic. As much as artistic and empirical passion socio-economic technologic and cultural developments, production technology, ergonomic and ecologic necessities, economic and political interests also play important role.

Design is in the position of a key which earns added value to the product and design determines the added value of the products. It is necessary that every produced product must have a philosophy, encompass various functions in it, and must present a good image aesthetically. That is why the design which used to be in production and technology in the past, now it is in the marketing and is unseperable part of it. Besides marketing conditions also require to compete by acquiring innovation, creating difference in design and creating brand [3].

In terms of ergonomics we see a rapid improvement and development in our country. In scientific world every day we find out new things about physical, physiological and psychologic features and needs of human body. In the light of this information ergonomic rules, propositions and advice are put together, and new stones are added to the base of ergonomic science. Humans are thinking creatures and continuously new materials, gadgets, mechanisms, processes and products are developed. All of these have to be evaluated during the design process in terms of ergonomy [4].

Nowadays, especially the importance imputed to the sectors in terms of cultural industries is increasing. Fashion design sector is also one of the sectors which gain importance provide economic contribution by feeding on creative capacity. Especially post modern consumption intertwined with fashion concept. Fashion has turned daily life into aestheticism and fashion design products have turned status and identity symbol into a mean to provide stylistic satisfaction. Together with comprising of variable consumption trends, in the textile and clothing industries instead of production the approaches focused on creating added value have appeared [5].

Because of the recent developments, in the competitive environment where added value is shaped with global networks that was created with cheap production cost in far east countries and China, in Turkey in textile and clothing industries it has become inevitable for structural change that is dependent on creativity and originality as well.

Nowadays, where consumer satisfaction has become a key concept for all products, new consumer profile has emerged who want original, different, and distinctive features and individual definitions. Together with the increase of the importance of fashion concept design extent of clothing products has become an important and sought after feature by consumers. It is difficult for the firms to adapt to the competition and sell their products which don't train designers, don't work with valuable designers, don't build up their original designs. For this reason, to be able to protect the market share and increase the market share they obtained with hard work, they have to present the original collections that have new and distinctive features [6]. In this occasion the importance of clothing designers comes into view.

In clothing designers' design approaches, as much as the image of the attire the practical usage of the attire must be an important criteria as well. Ergonomics which utilizes scientific branches like anatomy, anthropology, physiology, psychology and engineering can be said to have important contributions to the clothing topic. These contributions are related with mainly clothing physiology, anthropometry, functional features and product evaluation. When a garment is designed, to take into account of the colour, cloth, shape choices of the person which make him psychologically comfortable, to provide comfort and functionality by using anthropometric measures for the patterns are the clear indicators of garment–ergonomy relationship [7].

In this context, garment designer should take into account the concepts like the static and dynamic measurements of the body that is to say anthropometric measurements, body garment conformity, garment suitability. But in Kaya's 2007 study it was stated that in some designers' clothes aesthetic and symbolic functions might be more important than usage functions. Because by answering the demands of the consumers to provide satisfaction and create consumer loyalty are in the agenda of the many fashion firms and they develop this condition as a differentiation from the competitors and a product strategy to enhance competitive edge. On the other hand the designer in this process must reflect the factors in an effective way by using their creativity that may be effective on consumer behaviour. Koca and Koç [8] in their study by asserting that a clothing designer must have technological data like an engineer, sociological values like a sociology, sensing and evaluating feature like a psychology and appraisal capacity to overcome the barriers which may limit the creativity, remarked very disciplinary quality of the designer.

When clothing is defined as three dimensional covering of human body, it is evident that it has a different language apart from covering the body. To be able to feel comfortable inside the garments and move freely is quite possible with garments fitting properly, that provide free movements, are appropriate to whether conditions and comfortable. Ergonomic approach is an important factor in clothing design for social satisfaction as much as comfort and secureness [9]. Clothing comfort entails to produce and use materials/clothes which stimulate comfort feeling for individuals in terms of thermo physiologic, psychologic, aesthetic and usage conveniences [7].

When we check the works related to ergonomy and design, we see that there are various views and approaches in studying design problems. Brauer [10] sees that application of ergonomy takes place by way of design. Therefore, designers should understand other scientific branches which study human behaviour, psychology, kinesiology, biomechanics and human features. Now that designers use human features in creating a lot things they should take into consideration that in this context they contribute ergonomic data.

The clothes that are giving discomfort, restraining movements or creating barriers when working can be the main reason of the problems arising from garment suitability. The fitting problems of the clothing to the body both reduce job performance and create psychological and physical effects on people as well [9]. To be able to reach successful conclusions although a designer will need a great deal of knowledge and eager to use the knowledge from disciplines such as ergonomy, anthropometry, administration, psychology and engineering, this willingness doesn't show itself in practical phase. In this context in practical phase result must be reached by utilizing all of this knowledge [11].

Designers must proceed the process by taking into account of the expectations, user needs when designing the products. For the consumer centred design of the products, researched criteria are grouped under two different topics as performance and sentimental expectations in ergonomy literature. At this point the main purpose is to meet the expectations by incorporating ergonomic product design with the consumer in a best way at all the stages of the design process. Performance expectations are associated with efficiency and effectiveness aspects in the definition of usability [12] of ISO and sentimental expectations with satisfaction aspect.

*Performance expectations (Physical and Mental)*: Performance aspect of usability explains how effective and efficient it is, when a user uses a product to reach a known purpose. Performance is the utilization of data when a consumers use the product, how much physical or mental effort they use. Generally performance is calculated as objective and quantity in terms of the speed and accuracy of the job. Therefore, it is possible to evaluate whether performance expectations are met or not with standard methods.

*Sentimental expectations*: Image, impression and effect aspects are associated with the effect of the thoughts and senses or evaluated views about a product. In addition, subjective terms like satisfaction or preference are considered as a small piece inside the traditional definition of usability. Image, impression, and effect are broad concepts in both satisfaction and preference of a product and sentimental impression or sense which originates from the product. In this sense sentimental impression is the whole of psychologic reactions which the consumer shows for the design details [13].

In this context, with the aim of, a clothing designer can be able to add performances and sentimental expectations as added value to the clothes by reflecting functional and symbolic value to the designs in this study: in clothing design process, the evaluation of designers' ergonomic approaches are aimed.

## 2 Method

The designers in clothing industry are aimed in the evaluation of ergonomic approaches in clothing design process in this study's content and consisted with the designers of the big sized enterprises which are affiliated with TOBB (Turkish Union of Chambers and Commodity Exchanges). 135 designers who were randomly chosen as sampling from big sized enterprises clothing firms which are in operation in Istanbul, Bursa, and Corum in 2015 make up sampling group.

In compiling the data assessment instrument which is consisted with two parts is used by researchers. In the first part of the assessment instrument there are questions which address to determine the features of designers and their firms. In the second part there are questions to determine the designers' point of view toward ergonomics and ergonomic approaches in design process.

The data which was applied to designers by assessment instrument was analysed by using Statistical Package for Social Sciences. Data is presented as frequency tables, the relationship between variables $p$ values $< \alpha = 0.05$ and $p$ values $< \alpha = 0.01$ are interpreted by analysing on significance level by applying Chi square test.

## 3 Findings and Interpretation

A designer, with the creative power which is a kind of problem solving process, solve the developed design problem by using creativity and create various clothing designs which can convey messages to the people [6]. For this reason, designer's education, vocational experience and age gain importance.

Sampling group of which consist of 78 % female designers, 43 % have 0 and 5 years, 28.1 % have 6–10 years, have 20 % 16 years and above vocational experience. Even though 30.4 % of designers are 34–41 years of age and 28.9 % of designers are 26–33 years of age, and other age groups have an important significance and in the study it can be said that homogeneity is provided in terms of age. 35.6 % of sampling group is high school, 33.3 % is associate diploma and 28.9 % is diploma graduates are seen in Table 1. Sampling designers having the high

**Table 1** The distribution of work duration, age, education and gender of clothing designers

| Duration of work | f | % | Age | f | % |
|---|---|---|---|---|---|
| 0–5 years | 58 | 43 | 18–25 | 33 | 24.4 |
| 6–10 years | 38 | 28.1 | 26–33 | 39 | 28.9 |
| 11–15 years | 12 | 8.9 | 34–41 | 41 | 30.4 |
| 16 years and above | 27 | 20 | 42 and above | 22 | 16.3 |
| Total | 135 | 100 | Total | 135 | 100 |
| Education | f | % | Gender | f | % |
| High school | 48 | 35.6 | Female | 106 | 78.5 |
| Associate diploma | 45 | 33.3 | Male | 29 | 21.5 |
| Diploma | 39 | 28.9 | Total | 135 | 100 |
| Post graduate | 3 | 2.2 | | | |
| Total | 135 | 100 | | | |

**Table 2** The education level of designers related to clothing design

| Level of education in terms of clothing design | f | % |
|---|---|---|
| Yes | 55 | 40.7 |
| No | 80 | 59.3 |
| Total | 135 | 100 |

school and above education level is important. But having the designing education qualification will have a positive effect on clothing ergonomics and vocational skill aspect.

When Table 2 is analyzed, it is seen that 59.3 % of designers don't have education in terms of design. A designer is a person who creates clothes by combining knowledge, experience and senses with artistic elements and creativity, without thinking for fear of making an error, and by employing all sentimental and intellectual process as a whole [8]. Therefore to combine the features they have with creativity or the education which will develop the creativity is directly related.

Clothing designer creates the product by taking into account social, cultural, technologic, economic and aesthetic values of the society when designing the product. Interprets society's expectations according to his values, uses as a source the fashion trends and designs of international fashion centers. In this context, a clothing designer must have the approach and equipment who has technic, technologic, artistic, knowledge, and skill, plans clothing by taking into account consumer choices, fashion and usage area.

When Table 3 is analyzed, in ergonomic product definitions, most of the designers that are shown in no choice, is interpreted as the designers don't have the enough knowledge about ergonomy subject. Especially, it is remarkable that ergonomic product of the designers whose work duration of 0–5 years and 16 years and above and female designers whose age 42 and over are produced with the approach by taking into account of human health and are the products that are the most suitable to consumers. This result makes us think that the designers at the beginning of vocational experience have more knowledge about clothing ergonomy, on the other hand designers who perform their job have the knowledge through experience. In Chi square test result, it is seen that the designers have a significant (0.01) statistical relation between the demographic features and ergonomic product image.

When Table 4 is analysed, it is seen that clothing designers take into account ergonomic criteria a great deal. Especially it may be evaluated as a positive state that the clothing designers who don't have much experience as working years and age to have an image like this (0–5 years = 100 %, 18–25 years = 100 %). Besides, to market designed products with ergonomic approach will be able to be one of the factors which increase the competition in market condition where the product technical features are similar to each other. In this context, when the designers design their clothes, it is important that the designers take into account ergonomic factors.

**Table 3** Ergonomic product definitions according to demographic features of clothing designers

| Demographic variables | | Designers by taking into account anthropometric data | | | | | |
|---|---|---|---|---|---|---|---|
| | | Yes | | No | | $\chi^2$ | ***p*** |
| | | f | % | f | % | | |
| Education | High school | – | – | 48 | 100 | 69.794 | 0.000** |
| | Associate dip. | – | – | 45 | 100 | | |
| | Diploma | 3 | 7.7 | 36 | 92.3 | | |
| | Post graduate | 3 | 100 | – | – | | |
| | Phd | – | – | – | – | | |
| *Product which is more suitable to consumer* | | | | | | | |
| Education | High school | 17 | 35.4 | 31 | 64.6 | 10.802 | 0.013* |
| | Associate dip. | 9 | 20 | 36 | 80 | | |
| | Diploma | 3 | 7.7 | 36 | 92.3 | | |
| | Post graduate | – | – | 3 | 100 | | |
| | Phd | – | – | – | – | | |
| *Product which is more suitable to consumer* | | | | | | | |
| Work years | 0–5 years | 2 | 5.3 | 36 | 94.7 | 21.450 | 0.000** |
| | 6–10 years | 19 | 38.8 | 30 | 61.2 | | |
| | 11–15 years | 6 | 37.5 | 10 | 62.5 | | |
| | 16-and above | 2 | 6.3 | 30 | 93.8 | | |
| *Product with an approach by taking into account of human health* | | | | | | | |
| Work years | 0–5 years | 15 | 39.5 | 23 | 60.5 | 35.792 | 0.000** |
| | 6–10 years | 9 | 18.4 | 40 | 81.6 | | |
| | 11–15 years | 5 | 31.3 | 11 | 68.8 | | |
| | 16-and above | 27 | 84.4 | 5 | 15.6 | | |
| *To produce a good quality product* | | | | | | | |
| Work years | 0–5 years | 6 | 15.8 | 32 | 84.2 | 8.535 | 0.036* |
| | 6–10 years | 3 | 6,1 | 46 | 93,9 | | |
| | 11–15 years | – | – | 16 | 100 | | |
| | 16 and above | – | – | 32 | 100 | | |
| *Product which is the most suitable to consumer* | | | | | | | |
| Age | 18–25 | – | – | 33 | 100 | 18.571 | 0.000** |
| | 26–33 | 12 | 30.8 | 27 | 69.2 | | |
| | 34–41 | 15 | 36.6 | 26 | 63.4 | | |
| | 42 and above | 2 | 9.1 | 20 | 90.9 | | |
| *Product with an approach by taking into account of human health* | | | | | | | |
| Age | 18–25 | 12 | 36.4 | 21 | 63.6 | 28.345 | 0.000** |
| | 26–33 | 9 | 23.1 | 30 | 76.9 | | |
| | 34–41 | 15 | 36.6 | 26 | 63.4 | | |
| | 42 and above | 20 | 90.9 | 2 | 9.1 | | |

(continued)

**Table 3** (continued)

| Demographic variables | | Designers by taking into account anthropometric data | | | | | |
|---|---|---|---|---|---|---|---|
| | | Yes | | No | | $\chi^2$ | ***p*** |
| | | f | % | f | % | | |
| *To produce a good quality product* | | | | | | | |
| Age | 18–25 | 3 | 9.1 | 30 | 90.9 | 9.575 | 0.023* |
| | 26–33 | 6 | 15.4 | 33 | 84.6 | | |
| | 34–41 | – | – | 41 | 100 | | |
| | 42 and above | – | – | 22 | 100 | | |
| *All* | | | | | | | |
| Age | 18–25 | 15 | 45.5 | 18 | 54.5 | 14.436 | 0.002** |
| | 26–33 | 9 | 23.1 | 30 | 76.9 | | |
| | 34–41 | 11 | 26.8 | 30 | 73.2 | | |
| | 42 and above | – | – | 22 | 100 | | |
| *Product which is the most suitable to consumer* | | | | | | | |
| Gender | Male | 16 | 55.2 | 13 | 44.8 | 14.436 | 0.000** |
| | Female | 13 | 12.3 | 93 | 87.7 | | |
| *Product with an approach by taking into account of human health* | | | | | | | |
| Gender | Male | 5 | 17.2 | 24 | 82.8 | 8.940 | 0.002** |
| | Female | 51 | 48.1 | 55 | 51.9 | | |

**0.01 effective on significance level; *0.05 effective on significance level

**Table 4** The distribution of demographic features together with perspectives on ergonomic product design of clothing designers

| Demographic variables | | Do you take into account ergonomic criteria when designing products? | | | | | |
|---|---|---|---|---|---|---|---|
| | | Yes | | No | | $\chi^2$ | ***p*** |
| Work years | 0–5 years | 38 | 100 | – | – | 14.398 | 0.002** |
| | 6–10 years | 37 | 75.5 | 12 | 24.5 | | |
| | 11–15 years | 16 | 100 | – | – | | |
| | 16 and above | 26 | 81.3 | 6 | 18.8 | | |
| *Do you take into account ergonomic criteria when designing products?* | | | | | | | |
| Age | 18–25 | 33 | 100 | – | – | 14.301 | 0.002* |
| | 26–33 | 30 | 76.9 | 9 | 23.1 | | |
| | 34–41 | 32 | 78 | 9 | 22 | | |
| | 42 and above | 22 | 100 | – | – | | |

**0.01 effective on significance level; *0.05 effective on significance level

According to Chi square test, even though there isn't a relationship in terms of statistics between the gender and education level of the designers and ergonomic product design, it is possible to say that there is a statistical relationship according to work years and ages on 0.01 significance level.

Clothing comfort is to have cloth, pattern, sewing and comfort features of a clothing together with features which make the person feel comfortable. Therefore in addition to utilising anthropometric measurements, determining proper cloth choice and sewing features to provide clothing comfort they have to take into account the suitability to fashion when designers prepare clothing patterns.

Clothing comfort and thermo physiologic comfort: all of features like heat permeability, moisture drawing and washability and features like physiologic comfort, freedom of movement, functionality, aesthetics, suitability to age and consumer group, and psychologic comfort are the points designers should take into account.

In Table 5 it is greatly expressed that ergonomic product design have positive effects on firms and clothing designers and contribute a great deal to commercial performance. When the ratios are studied (in terms of the highest values: associate diploma and high school = 75.6–75 %, female 61.3–74.5 %, duration of work = 71.4 %, age 80.5 %) It is seen that ergonomic product design by clothing designers who are in all age groups, education level, and have duration of work is stated to contribute to both the firm and themselves. There is a statistical positive relationship between the designers who believe that ergonomic approaches will contribute to themselves in their activities and gender and education variable.

Besides in Table 5 it is seen that there is a statistical relationship on 0.01 significance level between demographic features and some contributions of ergonomic product design to the firm. It can be said that there is a statistical relationship on 0.05 significance level between the effect on performance indicators like sales, cost, and profitability and duration of work and age. Nowadays firms which develop new and creative ideas and implement these ideas will renew themselves all the time and succeed to survive in an increasingly competitive environment by being affected much less from the uncertain environmental conditions where the globalization increases.

Firms which offer new goods and services to the customers by utilising creative ideas will have big advantage in terms of sustaining the life, development, reaching goals, implementing customer needs [14]. It shouldn't be forgotten that the products which are produced with ergonomic approach is one of the important factors of creating advantage.

**Table 5** The contribution to enterprise and designer of ergonomic product according to demographic features of designers

| Demographic variables | | Do you believe that the ergonomic approaches will contribute to you in design efforts? | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Won't contribute | | Little contribution | | Contributes | | Contributes a lot | | $\chi^2$ | ***p*** |
| | | f | % | f | % | f | % | f | % | | |
| Education | High school | – | – | 6 | 12.5 | 19 | 39.6 | 23 | 47.9 | 22.345 | 0.001** |
| | Associate diploma | – | – | – | – | 34 | 75.6 | 11 | 24.4 | | |
| | Diploma | – | – | – | – | 21 | 53.8 | 18 | 46.2 | | |
| | Post graduate | – | – | – | – | 3 | 100 | – | – | | |
| | Phd | – | – | – | – | – | – | – | | | |
| *Do you believe that the ergonomic approaches will contribute to you in design efforts?* | | | | | | | | | | | |
| Gender | Male | – | – | – | – | 12 | 41.4 | 17 | 58.6 | 7.104 | 0.029* |
| | Female | – | – | 6 | 5.7 | 65 | 61.3 | 35 | 33 | | |
| Demographic variables | | How do you think the ergonomic design affect your performance indicators like sales, cost and profitability? | | | | | | | | | |
| | | Ineffective | | Little bit | | Effective | | Very effective | | $\chi^2$ | ***p*** |
| | | f | % | f | % | f | % | f | % | | |
| Education | High school | – | – | – | – | 36 | 75 | 12 | 25 | 23.038 | 0.006** |
| | Asso. diploma | 3 | 6.7 | – | – | 31 | 68.9 | 11 | 24.4 | | |
| | Diploma | – | – | 6 | 15.4 | 27 | 69.2 | 6 | 15.4 | | |
| | Post graduate | – | – | – | – | 3 | 100 | – | – | | |
| | Phd | – | – | – | – | – | – | – | – | | |

(continued)

**Table 5** (continued)

| Demographic variables | | How do you think the ergonomic design affect your performance indicators like sales, cost and profitability? | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Ineffective | | Little bit | | Effective | | Very effective | | $\chi^2$ | ***p*** |
| | | f | % | f | % | f | % | f | % | | |
| *How do you think the ergonomic design affect your performance indicators like sales, cost and profitability?* | | | | | | | | | | | |
| Work years | 0–5 years | 3 | 7.9 | 3 | 7.9 | 23 | 60.5 | 9 | 23.7 | 17.765 | 0.038* |
| | 6–10 year | – | – | 3 | 6.1 | 35 | 71.4 | 11 | 22.4 | | |
| | 11–15 years | – | – | – | – | 16 | 100 | – | – | | |
| | 16 and above | – | – | – | – | 23 | 71.9 | 9 | 28.1 | | |
| *How do you think the ergonomic design affect your performance indicators like sales, cost and profitability?* | | | | | | | | | | | |
| Age | 18–25 | 3 | 9.1 | 3 | 9.1 | 21 | 63.6 | 6 | 18.2 | 18.846 | 0.027* |
| | 26–33 | – | – | – | – | 27 | 69.2 | 12 | 30.8 | | |
| | 34–41 | – | – | 3 | 7.3 | 33 | 80.5 | 5 | 12.2 | | |
| | 42 and above | – | – | – | – | 16 | 72.7 | 6 | 27.3 | | |

**0.01 effective on significance level; *0.05 effective on significance level

## 4 Conclusion and Recommendations

The study in which the evaluation of designers' ergonomic approaches are aimed in clothing design process the following results were reached:

- Clothing designers who constitute 78 % female designers are at level of high school and above education but a big majority of the (59.3 %) didn't receive design education,
- Most of the designers intensify on the choice of no in ergonomic product definition and female designers whose work duration 0–5 years and 16 years and above together with 42 years of age and above see the ergonomic product as the most appropriate for the consumer and produced with an approach of taking the human health into consideration,
- Clothing designers greatly take into account ergonomic criteria,
- Ergonomic product design of sampling group have positive effects on firms and clothing designers and agree on the view that contribute to commercial performance,
- It is concluded that there is a great deal of statistical relationship between demographic features of designers with ergonomic product definitions, perspectives and contributions.

In international markets the firms face with a great deal of competition and it all boils down on the ability to analyze consumer needs and provide on time to be able to survive in this competitive environment. It is the consumer of all the starting and finishing point of activities of the firms. All the effort is for meeting and satisfying these ever changing needs of the consumer. Therefore it is important that clothing designers have this perspective and at the same time knowledge and skill to meet these needs and wishes.

As Kaya and Özok [15, 16] state even though design and ergonomy are two different disciplines, they work as a complementing part of each other of a whole. Whence ergonomy base on human focus in designing product, work place and systems, it must be seen as an approach or philosophy and design concept must always be seen as design for person. To design ergonomic product is possible with the education, therefore it is necessary for the designers to have an education in this field.

To train expert individuals as clothing designers to direct the society, with developed artistic and creative features, having cultural identity, and represent the country in international arena is possible with education. Clothing design education is important in terms of training designers who adapt to develop in technology, without ignoring the personality and cultural identity and inner person, have necessary technical knowledge and investigative spirit, prioritize innovation and creativity. When the research results are taken into account, it is possible to say that clothing designers in the design process with ergonomic approach will contribute to both firms and their own successes.

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# Costume Study on Spondylopathy Nursing Type Vest Based on Functional Costume Studies of Human Body Engineering

**Xiaoping Hu and Zhang Xiao**

**Abstract** High risk groups for spinal cord injuries and more enormous, spine care functional clothing in this area, however, has not been effectively developed. In view of this situation, the author puts forward the hypothesis that making a kind of sleeping vest that used at night to repair spinal diseases. For this vest, the author will collect data of spinal changes that caused by spinal disease and conduct the questionnaire survey on the spine health status of the young people who are 20–30 years old. According to the data and results of questionnaire survey, based on the requirements of human engineering, combined with the structure of the spine, design a type of vest that fits to the human body. During people's sleep process, spine disease is relieved through wearing and using the vest. And the health of the spine is restored. Besides, this study not only enriches the theoretical system but promotes discipline intersection.

**Keywords** Spinal spine disease · Medical functional clothing · Memory latex · Ergonomic functionality

## 1 Introduction

### *1.1 Purpose and Significance*

This paper tells the human body engineering application of spondylopathy of nursing type vest. The main purpose is to explore the requirement of how to nursing the spine disease patients in daily costumes without treatment in hospital. After the questionnaire investigation, a convenient and effective nursing type vest will be

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designed under the combination of human body engineering and costume designing which can improve the health of spinal issues and life quality for the spondylopathy.

The spine disease is one of the high incidence and non-fatal of community diseases in social group in recent years and it is often ignored by the public. In most people's view, the spine disease affects people's health and the quality of their work and life. However, They think it just caused by fatigue and overwork when they cervical vertebra feel dizzy, numb and stiff and it is acceptable. Meanwhile, as a result of wasting time to go to the hospital, which leads these group people become a spine disease patient in case of careless about their spine health. Spondylopathy is pretty difficult to cure, so to have more rest is the best way to get treatment for the spine disease. Therefore, under the passive situation, to design a new type nursing sleeping-vest which will provide an excellent effect to improve the spine disease by sleeping, also it has a great significance to protect these group people's health and get a better living level in the future.

### *1.2 Research Status*

To apply the memory material in function costume is the aim of this paper. It will improve the patient's spine status and relieve pain from spondylopathy and take a better living quality by the characteristics of memory material. These days, the memory materials are becoming more and more respected both here and abroad. As we know that memory materials are usually used in the car seat, backrest, U type pillow, mattress and other commonly used functional necessities, thus it can be seen more and more people have pay attention to the spine disease. As the spine disease can be have an excellent treatment by sleeping and the price of the major material of the memory material such as Memory Foam, Latex etc are too dearly, particularly for the price of Latex Mattress with more than thousand dollars, it is not afford by the normal middle-class people. Then, how to let this massive group people who have spondylopathy can enjoy the best sleep experience without to buy such an expensive memory material mattress? This problem could be solved by the memory material functional vest of the human body engineering design.

## 2 Etiology Overview of Spine Disease Patient Groups

With the rapid development of the Internet, convenience are bought into people's lives. At the same time, we rely more on the Internet and electronic products. Two of the most prominent device are the mobile phone and computer. Clinical research have found that when people are looking down at the phone, cervical spine would be equal to about 45 lb of pressure. "Phubbing" is the most recent vocabulary. Phubbing, (English name: Phubbing, words by Australia McCann and Macquarie dictionary teamed up carefully coined and to, described those who always phubbing to see their smartphone and snubbed their relatives) refers to those people regardless of everything, all bowing to see the screen-like smartphone, tablet PC or notebook surfing the Internet, playing games and watching video. For those who wants to fulfill their time by staring the screen, they share a common characteristic, their sight and the screen of the device seems to bound together tightly and unbreakable, causing the high probability of suffering spinal cord injury.

Some people in their 40s and 30s or even 20s years appeared recurrent symptoms like backache, stiff neck, dizziness and numbness of arms, while only few of the symptoms can be alleviated after clinical treatment. The most important causes of these symptoms is the problem of their spine. Data show that the current spine health has affected the quality of human life, spinal diseases and spine-related diseases have become c critical problem that can't be ignored. Spine is the middle axle of the human body, consisting 24 bones included cervical, thoracic, lumbar, sacral and caudal vertebrae, every piece of bone had six joints which can be rotated in 6 different directions. Therefore, our body can create 200 million kinds of permutation and combination of different rotating direction of the. Any one of the bones gets dislocation are likely to cause physical discomfort (Fig. 1).

Spinal disease appears in various forms. Cervical syndrome manifestations included headaches, dizziness, neck activity limitation and arm numbness; thoracic disease manifestations included back acid pain, shortness of breath, functional heart disease, gastrointestinal disorders, lumbar disease symptoms included back pain, lumbar herniation, lumbar spinal stenosis, limb numbness, and children's scoliosis or shoulders ranging differently. According to the survey from Beijing massage hospital, 97 % of the population over the age of 50 has the spinal diseases, in recent years, it has showed the younger tendency, among the people ages 40, more than 40 % of the them suffers spinal diseases. At the same time, Chinese children's development center also has a statistical incidence of our children's scoliosis rate are higher than 20 %. A person with healthy spine or not directly affect his quality of life, and the relationship between age and spine will gradually appear. According

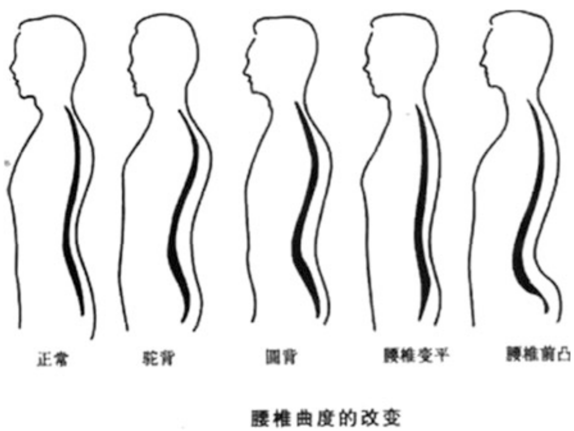


**Fig. 1** A lumbar curvature change

to a scientific prediction, people's life should be about 120 years old, but the average life expectancy of Chinese people is only about 72 years old, in which the spine problem causes us to shorten or life expectancy nearly 1/3. So it's very important to keep your spine healthy.

## 2.1 Necessity of Designing the Nursing Vest for Patients with Vertebral Disease

Through a questionnaire survey, we found that most people continue to use electronic devices for longer periods (Fig. 2). The sustainable use of electronic equipment for more than 60 min for 73.91 % among those people, while continued using for 30–60 min reach 4.35 %, continued using for 20–30 min get 13.04 %, continuous using for only 20 min below are less than 8.70 %. It is arguable that due to the popularity of mobile devices and the rapid development in recent years, people rely more and more on electronic devices, this is the main reason why the spinal problems are increasingly large-scale and younger these years.

Due to a series of symptoms caused by vertebral disease which can lead to poor sleeping conditions with spinal diseases. Many patients will have insomnia symptoms in the night. At the same time, a lot of patients mistakenly thinking that harder mattress will aggravate the spine disease in patients with poor sleeping quality, and choose soft mattress, but the reality is that using soft material for a long-term will aggravate the condition of spine disease. So we make an issue about "Will a good mattress directly determines the spinal health and the quality of your sleep?" (see Fig. 3). 52.17 % people think a good mattress will directly determine the spinal health and quality, and 4.35 % people think that the mattress does not affect anything, while 17.39 % people think the allowable conditions will consider the purchase of a higher comfort of the mattress. 13.04 % people think that the mattress is very important for the health and sleep status for spine. The rest of the

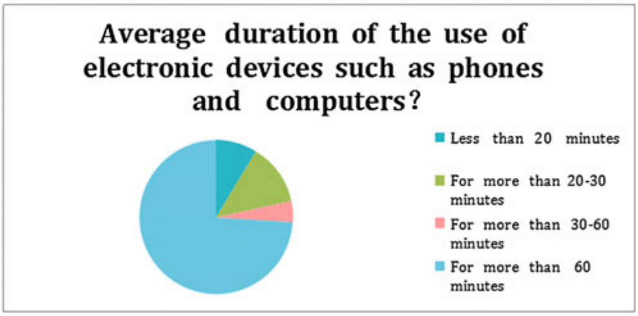


**Fig. 2** Average duration of the use of electronic devices such as phones and computers?

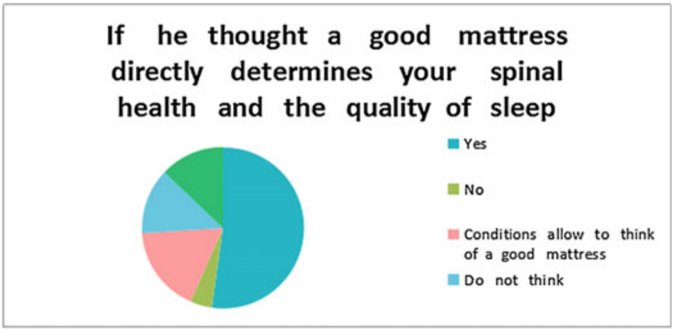


**Fig. 3** If he thought a good mattress directly determines your spinal health and the quality of sleep

people think otherwise. As it is shown in the issue, people gradually began to pay more attention to the mattress for the health of the spine to help.

Considering the above mentioned, we draw a conclusion that people concern more about the spine's feeling during their sleeping hours, while a comfortable and ease sleeping experience can also somehow fix the uncomfortable feeling. The mattress sold by market contains wood, palm, spring-mattress, Memory Foam and latex. Mainly the memory foam and latex are the most comfortable and most expensive one. So we can design a nursing vest made from memory foam or latex to replace the expensive mattress in a certain extent. Beside its low cost, portable and suitable for all ages patients, it can also afford efficient heat preservation for the patient's back and spine.

## 3 The Material Selection of Vertebral Disease Nursing Vest

Considering comfortable mattress mainly in memory foam and latex, we select memory foam and latex in vertebral disease nursing vest. These kind of material, which with the memory characteristics, can change its shape according to the sleeping curve when human fall in sleep. They can support the patients' spine, and then improve the stiff spine and poor sleeping quality.

Memory foam, a kind of polyurethane macromolecule with open cell structure, having special viscoelastic properties, very soft and have a strong shock absorption ability. This material is very sensitive to temperature, so it is also known as temperature sensitive memory foam. Open-Cell molecules "flow" and shift to fit the pressure on the contact surface profile when the external pressure occur. It will slowly return to its original shape after the pressure relief. So this kind of material also known as "slow spring back foam" (Slow Rebound Foam).

This feature allows memory foam showed: as a shock buffer material, there is a strong impact energy absorption capacity, and to contact with the pressing matter a small rebound. The rebound of buffer material is the main harm for the object or human body when they face to high impact. As the cushion material, it subjected to pressure approximate static pressure. And under this kind of pressure, the molecular structure of memory foam will be "flow", deformation to fit the pressure profile. Supporting point will spread to the whole contact surface, so that the pressure to be dispersed in the contact surface. This feature is known as the "Pressure Disperse Characteristic". Because the pressure is uniformly distributed, the body does not exist stress concentration points, comfort greatly improved when the people sitting on the memory foam material cushion. It reached a good preventive effect for long time high pressure compression which leads to the blood circulation blocked bedsore. This material even softer than ordinary after a special modulation improved. At the same time, the material Open-cell molecular structure, is similar to the cellular structure of the human body, that make it have good human compatibility, which makes memory foam materials are widely used in the field of medical aid.

These characteristics are doomed to this material will play an increasingly important role in people's life, today's fact that it is true. (1) temperature sensing characteristics of the human body temperature induction, gradually become soft, and absorb the human body pressure will be adjusted to the most comfortable posture state. Oppression of sinking to below not exposed to temperature, which remains fully support force; (2) viscoelastic property refers to the product pressure and subsidence, but not a strong anti stretch (such as clay compression); when the pressure is removed the products will be gradually restored to its original shape (such as spring recovery); the "slow rebound" called "zero pressure sponge", meaning is lying in the above feel as if floating in the water/or cloud.

The density of memory foam have a great effect to properties. The heavier, more expensive, and higher performance. In order to have enough supporting force as the use for human, it need at least more than 80D. Top of the slow rebound products reach 120D. Different production process, product density, accessories selection, etc., also led to the slow rebound in different manufacturers of product quality gap is very large. We recommend consumers to choose famous brand, with corresponding test report.

Some customers feel unnatural when they use the produces at the beginning, because they get used to the height of traditional pillows. They will get used to the produces after 3–5 days and the cervical vertebra feel relaxed in the morning.

The main advantage of the Latex material: (1) Prevent mites prevent bacteria. According to the medical report, pillows, bedding are a hotbed of bacteria and dust mite and pillow for three years contain 10 % mold, mites feces and the numerous bones of mites. According to the medical information, the harm of dust mite deeply 12–16 % people with allergies, and 25 % of these patients are caused by house dust mite allergy; in addition, 90 % asthma patients and even more are caused by house dust mites. Because latex oak protein can inhibit bacteria, allergic original latent, mites breeding and it has no static and comply with environmental requirement. The Oak protein scattered natural milk flavor which is benefit for the person who has asthma and allergic rhinitis and other respiratory system disease (2) Breathable. Natural latex pillow has thousands of tiny mesh structure of vent. These holes can shed human emissions of heat and moisture, promote natural ventilation, provides natural air conditioning system, and keep the air inside the pillow fresh and healthy.

## 3.1 The Conception and Design of 1 Vertebral Disease Nursing Vest

We begin to design the body of the vertebral after determining the material of the vertebral body care vest. Its appearance is no different from the ordinary vest. However, the back design is originate from the human engineering, Mold making is according to the normal human spinal curvature, through changes in the thickness and design a filler placed back into the back. The filler can make the patient's spine get a little more comfortable and get a certain recovery unconsciously during the sleep, especially the lumbar part of the support, while improving the situation of lumbar disc herniation. However, because the memory foam and latex material could not be washed, so there is a removable design. The external material of the vest is mainly based on velvet, which gives the skin a better feeling. The button design with felt buckles due to the operation of ordinary button is inconvenience to the elderly and children. The main profile of the spine care vest is a loose fitting, in order to avoid the discomfort of the user in the design of a tight bundle during sleep. The main design is as follows (see Fig. 4).

## 3.2 The Significance of Spinal Disease Nursing Vest

Spinal disease nursing vest can improve the health of patients and the abnormal curvature of the spine. A memory vest complied with human body engineering can not only alleviate the lack of sleep in patients with disease of the spine, but also relief the mental state of patients with. The making of spinal disease therapy vest is a process of creation, at the same time it also follows the principle of the human body engineering. The fundamental purpose is to improve the quality of life of patients who has disease of the spine, and then improve work efficiency of the group. It has a certain significance to the development of functional costume that combining functional products with humanistic care and providing scientific basis for functional costume.

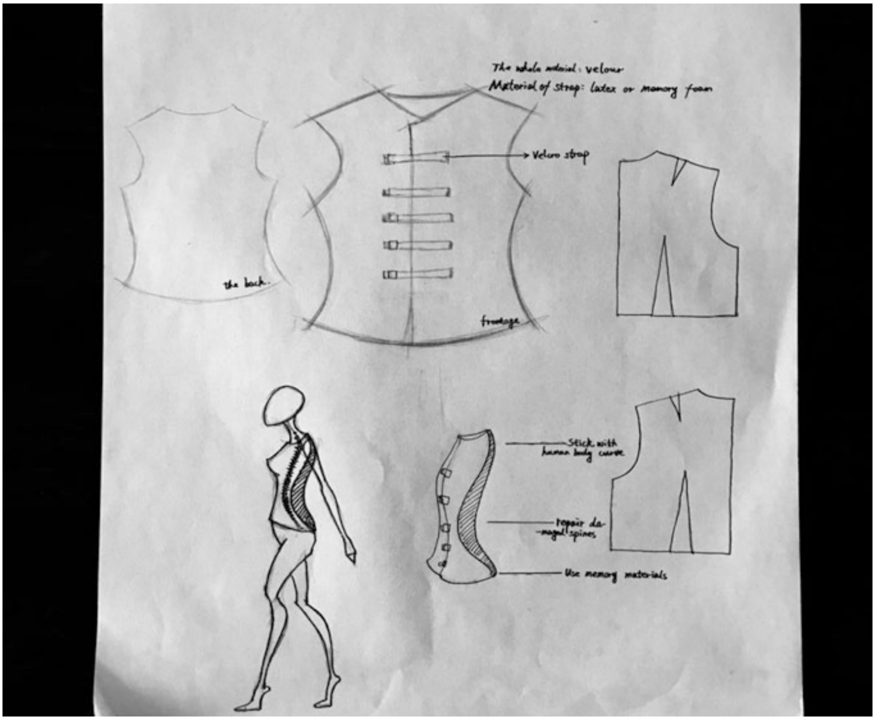


**Fig. 4** The button design with felt buckles

## 4 Conclusion

Due to the limitation of time in grasp and implement production technology while my cross-disciplinary knowledge structure system is still not complete enough, especially on this topic about the research of various spondylopathy patients figure data is not comprehensive, so many problems and shortcomings appears in the study which mainly reflected in the subject of research of the relevant professional knowledge structure, and the various ages of vertebral disease patients are not described in detail. Therefore it needs to be further improved and strengthened. I sincerely hope that through the investigation of the spine disease and the nursing vest needs and on spine disease and the material information collected for the nursing vest design, we can seek for a type of suitable clothing for spine disease nursing while combining the design and ergonomics human engineering for the spine patient community. And finally I can expanding my own force for those people suffering this problem.

# Exploring the Impact of Lifestyle on Fashion Consumption Behaviour for Older Chinese Women

**Minzhi Zhang, Sonja Andrew, Gary Warnaby and Simeon Gill**

**Abstract** Due to changing lifestyles in the ageing society in China, consumption behavior for older people tends to be varied rather than traditional, especially in the fashion industry. This research provides a qualitative insight into older women's (between 55 and 70 years old) lifestyle, and their attitude towards fashion-related consumption in China. Regarding specific cultural background, generation, value conception and social environment, both generally and individually, fashion consumption behaviors are explored, with changes on dressing preference summarized. The results demonstrate several factors about lifestyle, which can be used to segment the ageing fashion market, and target potential consumers in the future.

**Keywords** Fashion consumption · Lifestyle · Older women · China

## 1 Introduction

According to the World Health Organization [1], the increasing in older population is a worldwide problem faced by approximately one-third of countries and regions. In contrast to the rest of the world, more rapid and dramatic demographic changes have appeared in China that have led to an old-age society. The Chinese older population grew at an annual rate of 3.2 %, which was almost three times greater than the rest of the world [2].

Apparel manufactures mainly focus on younger markets [3, 4]. Fashion is a word that is usually linked with young and beautiful women. However, older people also want to dress fashionably themselves and feel involved in fashion [5]. They are interested in the activity of purchasing clothes, but less attention is paid to this niche market [6]. The silver market for older people is not homogeneous. The diverse characteristics of the older population tend to be categorized into several narrow groups, owing to heterogeneity in product preferences and consumption behaviours.

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Schewe [7] stated that the priority of segmenting a market was to examine an individual's sense of self and important lifestyle issues. Stevens et al. [8] also described individual lifestyle and attitudes toward self, work, home, family and peer-group identity as essential variables that affect consumption behaviour.

Great changes in older people's lifestyles have taken place in China particularly since the Open-Door policy. Since this economic reform, China has been transforming itself from a subsistence economy to a consumer economy [9]. Benefiting from the national social insurance system, older people have a more stable income, and an enhanced standard of living [10]. An obvious increase in both the individual buying power and collective purchasing power of older people has appeared [9]. Thus, they no longer behave as traditionally expected, which has led to more diverse consumption behaviours [10, 11]. 71.9 % of the female older population in China considers it necessary or essential to pay more attention to their appearance, e.g. their clothes and make-up, as they get older [12].

There is relatively little published academic research about the older Chinese population in terms of fashion-related consumer behaviour, and most previous research has concentrated only on the context of older Western people. Therefore, in order to understand how lifestyle effects fashion consumption in older Chinese women (between 55 and 70 years old), further investigation needs to be conducted.

## 2 Research Objectives

Older people hold different perceptions and consumption behaviours than other cohort groups [13]. Due to sophisticated and heterogeneous features such as prioritizing quality of products, the silver market cannot be segmented via traditional demographic methods [14, 15]. Five key variables are highlighted by Fitzgerald Bone [16], which included two demographic variables (discretionary income and health), two lifestyle variables (activity level and discretionary time) and one psychological variable (response to other people). The PIL (Physical, Identity, and Lifestyle) model was presented by Rocha et al. [17] to analyze ageing consumer's preferences. Lifestyle variables including indicators like moral conventions, versatility, and ethnicity were taken into account to address the body/mind relationship for older consumers during purchasing. Research indicated that older consumers strongly wished to express their individual taste, lifestyle, and personality through high quality garments [5, 6, 17]. They tended to buy brands that projected their self-image and status to others. Clothing can also encourage active social interaction with their peers [18]. Thus, expressing a positive appearance via clothes is important for older people and their appearance should be as close to their psychological perception of their lifestyle as possible.

For fashion-related consumption, two aspects; physical status and psychological characteristics, directly influence older people's lifestyle. Tallmer and Kutner [19] pointed out that the physical health status of older people has a dominant effect on their interpersonal interactions and lifestyle compared to widowhood, retirement and age. Any illness will negatively affect an older person's quality of life [20]. Hence, life satisfaction relies heavily on good health. In addition, the body shape of older people changes more obviously as they age. The main differences for women are a significant increase of bust, waistline, and hip circumference, and a dropping hipline [21]. No matter whether people take regular physical exercise throughout their life, an increase in girth and a decrease in height for older women are common, and considered to be irreversible and permanent [22]. Despite ageing, older women may still consider themselves to be as beautiful as they were in their younger years. Older people are generally more confident in knowing what they prefer in terms of their living environment. Older people are generally more confident than younger individuals in making decisions for themselves and being sure that they are right [23]. Most older consumers in China desire to be thought of as 'young' or 'vibrant' [24]. Ying and Yao [24] found that 51 % of older Chinese women considered themselves mentally younger than their age, and the average disparity was 10 years. Furthermore, older people appreciate a more convenient and comfortable lifestyle. They have more spare time to communicate with their family, friends, and neighbours, especially after retirement. Those interactions bring more satisfaction and increase social activity. [16].

As the first step in the project to develop a fashion design strategy for the older female Chinese population, this research focused on providing a qualitative insight into older women's lifestyles, and their attitude towards fashion-related consumption in China. The purpose of the study was to explore the connection between an individual's lifestyle and their fashion consumption behaviour, this included fashion preferences and dressing requirements. The research focused on three interlinked questions:

**Question 1**: What are the differences in current fashion preferences and dressing requirements in older Chinese women compared to when they were young women?
**Question 2**: Regardless of the different lifestyles of older Chinese women, what are the general characteristics of fashion consumption for this section of the population?
**Question 3**: What kinds of lifestyle lead to specific characteristics of fashion consumption for older Chinese women?

## 3 Method

The study employed qualitative research methods in order to produce a data set. Face-to-face interviews were conducted to gather in depth personal accounts of individual fashion preferences, using a sample of older Chinese women. This method was favoured because of other companies successfully interpreting their customers' needs through qualitative methods, by analysing consumers own voices, rather than using less personal numerical data [25]. As the interview process was the first step in the whole project, eight open-ended questions were selected in the lifestyle and fashion attitude section (Table 1). This was developed based on

**Table 1** Semi-structured questions in the lifestyle section

| | |
|---|---|
| 1 | Please describe your daily routine (including work and social activities) |
| 2 | How does your daily life influence your clothing choices? |
| 3 | Please describe your favorite outfits in different seasons (spring/summer and autumn/winter) |
| 4 | Why did you choose these garments? |
| 5 | How important is fashion to you? |
| 6 | Do you follow fashion advice? |
| 7 | What are your priorities when purchasing clothes? |
| 8 | When have you changed your clothing choices in the past? How have these changed? Why? |

previous literature. This focused on how the daily life of older Chinese women influenced their fashion preferences and their dressing behaviours.

Face-to-face interviews took place at participant's homes. For safety, a third party was present in every interview. Each interview was approximately 15–20 min in length. Participants were also encouraged to add any additional information they considered important. Personal information like background and living status were also collected via the interviews.

21 Chinese women aged between 55 and 70 years old were involved in the research. They were equally divided into three age groups, which were 55–60, 61–65, and 66–70 years old. The participants were recruited using opportunity sampling, targeting personal connections, residents' committees and an art group, who fitted the participant criteria. All the participants were settled in Beijing and came from different social backgrounds. Based on their incomes, most of the participants were middle class. Their monthly incomes ranged from 2000 RMB, to over 10,000 RMB. Nearly half of the women had a secondary education, and more than a quarter held a university degree. The majority were retired and used to work as teachers, factory workers, or administrative staffs. Others still worked for their former employers, or new organizations. Some of them did full-time jobs and some were part-time. Most lived in a mixed-generation family containing their husbands, their parents, their children, or their grandchildren. The maximum family was six members, and the minimum was two.

Each interview was audio-taped and transcribed in Chinese. All these Chinese texts were then translated into English. As the research questions were descriptive, qualitative content analysis was conducted for systematically describing the meaning of this collected textual material. For reducing the material, data was classified as instances of the categories of a coding frame [26]. Coding frame was evaluated and then modified for three times. After that, important characteristics were identified by summarized semantics and the results were presented in a frequency format [27]. In this paper, in order to ensure confidentiality for participants, a random ID system was implemented. All participants were anonymous and referred to in digits.

## 4 Results and Discussion

### 4.1 Differences in Preference Since Growing Older

Of the 21 participants in the study, 15 expressed a significant change in their clothing, preferences as they grew older. The majority felt that the difference in lifestyle between working and retiring lead to the change. Participant 14 said that ‘after I retired, I had more time to have fun with my friends and enjoy my life.’ She felt more relaxed without being bothered by work. Her dressing style became more casual, leisurely and sporty. This contrasted to her formal monochrome uniform she wore at work. There was no longer any need to dress formally on a daily basis. Nearly half of the women preferred to dress in vibrant colours as they reached retirement, rather than the dark and neutral clothes they previously favoured. Both Participant 13 and 14 mentioned that bright colors like burgundy and deep rose could warm up their faces and make skin look healthier. ‘Especially for taking photos outsides, I dressed up more shiny and bright’, participant 13 said. However, the participants did not favour bright neon colours. This does not support McCann and Bryson’s [28] findings which concluded that older women enjoyed dressing in neon colours. Furthermore, seven participants described their preferred style as ‘comfort’. They said that it was important to dress properly for movement or gentle physical exercise. Some also expressed an interest in separate garments with a slightly loose fit. Similarly, when participant 11 talked about style, she stressed the need for comfortable clothing when engaging in daily fitness activities.

> Definitely changed, before retirement, I always wore business suits, I was especially fond of skirts. My business suit skirts are in various colors. I’ve got a long Qipao-style skirt in pure white. I paid great attention to my dressing. But after I became over 60s, I don’t think these working uniforms suit me any longer. Because when I play with my granddaughter, I need to squat or stand up frequently. Sometimes, when I do sports or any other physical exercises, it is inconvenient. So my current dressing style is becoming more casual. I suppose it is changed for two reasons. One is I spend more time with my little granddaughter, since she came into my life. The other one is that comfortable sensation became more and more essential for me, as I grew older and older.

Some participants mentioned that their dressing styles were conservative when they were young. As there were few styles to choose at that time, everybody had to wear similar clothes to each other. However, as these women grew older, they strongly desired to have an individual and distinctive style. Participant 8 attributed her change in style as she got older as a way of compensating for how she dressed as a younger woman. She said ‘as reaching my age, I feel I need to recall my young spirit. I must keep active and vital. If I don’t express my vigour now, there is no more time left for me. I believe I’m not the only one who thinks about it.’ It was true. Participant 27 mentioned although she was 70 years old, she never shopped in stores that were marketed for older women. ‘When I was young, I believed I would become an old woman before I was 60. However, nowadays I don’t feel old at all. I even dress more adventurous.’ Compared with older people, the youth had a stronger self-awareness when making purchase decisions. In terms of fashion, they tended to follow the latest trend and wanted to be unique among their social group [23]. Participant 1 dressed distinctively when she was younger. She described her style as becoming progressively more similar to those her age as she got older. Participant 1 described this as a psychological change, which was subjective.

> My dressing preference was consider as a little weird by others when I was young. They said my clothes were uncommon and outside public aesthetic acceptance. Actually I don't agree with that and I don't really care about it. I suppose I'm already into dressing a certain way these last two years. Since two years ago, I started dressing more similar to my peers.

Some participants expressed they were more willing to share fashion information and dressing experiences with their friends and neighbors. 'I like go shopping with my former colleagues. Sometimes we are fond of the same style. We try. It suits us well. Finally, we both buy the style only in different colors', participant 5 said.

Although more than 80 % of the participants implied they did not suffer from any severe illness, their current health conditions had become worse compared to their youth. Approximately half of the participants said that their choices in clothing were affected by health conditions or body shape. For example: since growing older, participant 2's legs became curved and a little deformed. In order to cover up the weakness, participant 2 did not wear leggings any more. Stretched jeans in a loose fit became her first choice. Participants 23, 3 and 24 also mentioned difficulties with their knees and legs.

Some women expressed particular interest in long-length outwear for winter. For instance: participant 27 mostly wore an ankle-length puffer coat in December and January to keep warm. Most women in the interviews also mentioned that they preferred high quality garments especially in winter. 21 participants preferred to spend money on a few high quality items, rather than many lower quality items. Participant 22 said that she had plenty of clothes for every occasion, and that any new clothes she bought must be more luxurious than her existing clothes. Otherwise, she would prefer to wear her old clothes. Participant 27 also held a similar opinions:

> When I was young, I often bought clothes without any specific requirement. But now, I do not shop impulsively as before. Only if I need it or I am really satisfied with it on all sides, I will buy it.

Based on the above changes in dressing preference by age, all the characteristics were summarized as key words in Table 2. Seven features were classified into two categories; clothes preference and dressing habit.

However, four women's dressing preferences remained very similar to when they were young. Participant 27 said that being engaged in arts-related work, fashionable and avant-garde dressing had become a strong interest in her life for more than thirty years. Participant 4 spent much of her time working hard at her job when she was younger, and was not interested in fashion. She now devotes her time to taking care of her grandchildren; therefore, dressing attractively is no longer a

**Table 2** Changes on dressing preference by age

| At a young age | In older age |
|---|---|
| *Clothes preference* | |
| Formal style | Leisured style, casual, sporty |
| Fitted cut | Casual fit, comfortable, easy to move in |
| Black, white, grey, neutral colors | Colorful (but excluding neon colors) |
| *Dressing habit* | |
| Conservative | Recalling when young and active |
| Self-awareness | Shared with peers |
| Less concerned about health and body | Dependent on health condition |
| More items of low quality | Fewer items of high quality |

priority. Alternatively, participant 6, expressed her strong loyalty to her fashion preference throughout her adult life.

> Since I was young, I never bought any clothes which I didn't like in the following two years. I believe once I decide to buy some clothes, I will love them forever. I'm the person whose emphasis is on the sustainability of the clothes rather than the trend at any one time. My clothes must be in a classical style and be able to last forever.

## *4.2 General Characteristics of Fashion Consumption*

**Comfort**: When asked about the reason for purchasing their clothes, the word 'comfort' was highlighted by all the participants. For the need of comfort, textile selection is key to increasing the tactile pleasure of clothing for older people. As a previous research showed by Liu and Liu [3], the first choice on fabric was still pure natural fabrics like cotton, wool, silk and hemp amongst all the participants. 'Cotton is the best', said participant 6. Although some women admitted to owning outer wear made from synthetic fabrics, no one stated that their underclothes were made from non-natural fabrics. Participant 3 was in favour of mixing cotton with silk:

> Polyester must be avoided. For ageing people, our skin is quite dry. Those synthetic fabrics are bad for our skin. It's easy to build up static. Especially in winter, my skin often peels. It's quite uncomfortable.

**Ease of wear and care**: Many participants mentioned the importance of dressing in a convenient way at their age. The feature of convenience encompasses being easy-to-wear, easy-to-move in, and easy-to-clean. For easy-to-wear, cardigans were more popular than pullovers. Zips in the side seam were also better than zips at the center back. The findings are consistent with research from McCann and Bryson [28], who stated that due to loss of strength in older people, it was essential to consider how to fasten and package garments more simply and conveniently. None of these women preferred tight clothes to loose cut styles. Participant 1 said that only if enough space was left between fabrics and her body, she could move, walk and do exercise flexibly. The enhanced ease of movement in clothes was needed by older women who suffered from arthritis and/or joint issues [21]. Only participants 1 and 6, implied that they did not show a preference for their clothes to be easy to care for and to clean.

**Moderate coverage**: Many participants mentioned that they were inclined to wear clothes that covered most of their body. Similar to previous research [3, 4], dresses with sleeves and longer trousers were favoured by most women. Clothes that exposed too much of their body were rejected by all older women in this study. However, although older women were more likely to wear the clothes in a longer length, oversized clothes were avoided. Thus, the clothes with a moderate coverage were ideal for the older women. According to the participant's feedback, three main reasons were outlined as contributing to this preference. The first reason was based on an aesthetic aspect. Participant 3 expressed her fear of showing her ageing body:

> I know a short length coat is popular in some seasons. But it is not proper to wear it at my age. I need my coat to cover my bad-looking parts like my prominent abdomen and increased hip, so other people can pay attention to the good-looking parts of my body.

The second reason was concern about health. Participant 23 said that she wore a quilted waistcoat with extra shoulder paneling, as she was worried that her upper body (especially the shoulders) would get cold. The last reason for this preference was because the participants viewed short-cut clothing as socially acceptable for younger women and not older women, as this doesn't adhere to the expectations of how older women dress.

**Group preference**: Although general fashion market segmentations were varied, the research showed that choices in clothes tended to reflect unanimous group preferences for the older women. Most older women tended to express their mature image as a positive feature, in terms of their style. Older women purchased their clothes with specific ideas of what they wanted [3]. In total, 19 of 21 participants in the study said that 'simple, generous, and elegant' styles were what they preferred. This style was averagely described as a mid-length T-shirt or polo, matched with a pair of casual three quarter length trousers in summer. In spring and autumn, cardigans were worn with waistcoats underneath a coat. Wool or cashmere sweaters were worn with puffer coats in winter. It seemed that the decision to wear multiple layers in winter tended to be a trend amongst older women. Female friends and relatives opinions were highly regarded and tended to easily influence the older women's fashion choices [23]. In the study, eleven retired participants mentioned they joined different activity groups like dancing, singing or drawing on weekdays. Even though most of them only spent three or four hours a week with other peers in the same group, their clothing style was influenced by each other and tended to be similar. Participant 13 was the most active person amongst all the participants, she preferred to be well-dressed when she danced in the community group. She said 'at first, I was the only one who wore a long rose pink dress. In contrast, my friends were afraid of dressing colorful. But now, they start dressing more adventurous than me.' Some women also reported that showing respect to others through dressing similarly was an important factor when they chose what to wear. The women wanted dress in a similar way as they believe that this makes their peers happy, as this shows a special consideration towards the person they are meeting with. Meeting different kinds of people affected participant 7's clothing choices:

> The clothes I wear depend on what kind of people I'm going to meet. If I plan to have a talk with an office lady, I will dress formally. If I go out with a person who lives a simple life, I will wear casual clothes. I insist on dressing properly for the people I meet. Sometimes if it is in the right season, I will probably put on the clothes which we bought together. I suppose she can also remember our previous shopping experience and I'm really happy.

**Dressing for different occasions**: Four women reported that they didn't attend any formal occasions anymore. Twelve participants reported that they went to formal events, but infrequently. For daily life, most participants wear four or five key pieces in turn and do not change their clothes often. However, although dressing formally was infrequent, the majority stated that they dressed in different styles depending on the situation. Participant 11 said:

> If I go out for dinner, I dress up a bit. I wear elegant clothes with nice quality at this moment, because I need to go to such a nice restaurant or a decorated hotel. However, if I go out for swimming or taking a bath in a hot spring, I normally carry a backpack and put on my sportswear or casual clothes.

## *4.3 Lifestyle-Specific Characteristics of Fashion Consumption*

When some participants discussed the importance of fashion, it was not about following the latest styles from the runway, or dressing in the best-selling items. It was more about somewhat following fashion trends, but adding a sense of their own style. For individuals, ideas about how to dress as older women varied. In the research, variables including individual's age range, education, income, and former occupation didn't impact on the disparity between the older women's fashion preferences and consumption behaviours. In contrast, it revealed that the differences in dressing were influenced by their current lifestyles.

**Working versus retired life**: For dressing preferences, the most obvious influencing factor was whether they had a job or were retired. It suggested that compared with retired participants, employed women spent more time and money on dressing properly, according to their working environments and job positions. For example, participant 9 and 14 wanted to present a serious persona at work. They said that they cared about whether the clothes made them look professional. They were less concerned about following fashion trends with their working attire. However, participant 4 (retired) expressed her focus on leading a busy home-life, which included daily housework and caring for her husband. She normally wore household apparel made from cotton, at her comfortable home. Her main external activity was buying food for her family at the market. She said, 'when I go out, if I feel comfortable and convenient in my clothes, that will be enough'.

**Extrovert versus introvert**: Personal character influenced individual's dressing preferences to an extent. Active older women showed contrasting fashion consumption behavior compared to more introverted women. The former group mainly took part in different social activities. Public square dancing in a park or community based dancing were the most popular activities for women between 55 and 70. In the research, 13 women went dancing at least once a week. All of these active ageing 'dancers' showed an interest in dressing well. Some of them expressed that they began to wear more attractive clothes when they started taking part in these social activities. 'I once didn't care about my dressing style at all. But, after I started learning dancing, I paid more attention to my clothes. I was influenced by my dancing partners. Because they all dress pretty, I need to follow them', participant 15 said. These active women described their clothes as more colorful, and the patterns were more adventurous than before. They were also interested in going shopping together and sharing their fashion ideas with their peers. However, the minority were introverts and tended to spend time alone. They had hobbies such as, reading books and drawing pictures. This group of older women insisted on maintaining their own dressing style. The evidence showed two antitypes of dressing style. The introverts who had a strong sense of personal style, like participant 6, dressed elegantly. Another introverted yet conservative person like participant 9 wore generic old-fashioned clothes, like plain sweaters and polos without any design details.

**Solitude with partner versus extended family**: With respect to the living situation (who they lived with), seven women lived in a large sized family (more than five family members) with their children and grandchildren, one participant lived alone, other participants all lived in relatively small sized families (two or three family members). Among small sized families, six women lived only with their husbands, and two only with their unmarried children. The other four women lived with their husbands and unmarried children together. The feedback from the interviewees revealed that older women in large families did not prioritise their clothing or sense of style, this was due to the assumption that they should take main responsibility for performing household duties, and monitor the health of other family members, rather than be concerned with their own appearance. However, women who lived with their husbands were more willing to enjoy their ageing lives. The majority of this group of women showed they had more interaction with their friends in their older years, compared to when they were younger. Clothing became a mediator between older women and their relatives, thus, these women were more adventurous with their personal style, and were more willing to follow current fashion trends. Furthermore, fashion consumption for older women was also affected by whether they had daughters or sons. The study showed that all participants who had daughters frequently went shopping with their daughters; however, those who had sons bought their clothes more often by themselves. Daughter's opinions of the clothes were essential for older women when making a purchasing decision. Participant 11 explained that although she loved browsing in clothes shops and following the latest trends, she always asked her daughter's opinion before she bought an item. If her daughter did not seem keen on an item, she would not purchase it. Participant 5 also expressed that she loved to share clothes with her daughter because they have similar body shapes; she considered purchasing new clothes as also for her daughter whom could wear occasionally.

**Good health versus poor health**: For example: participant 23 had difficulty walking, because of the pain in her legs. She did not want to attract people's attention to her walking posture. Although participant 23 had a strong desire to dress fashionably and elegantly, she instead worn plain and simple clothes in her daily life. Participant 24 also mentioned that her dressing choice was changed obviously due to her physical status. She said, 'when I retired, I used to go out for dancing or taking exercise in the park nearby every day. I followed the latest fashion trend and wore nice clothes when I went out. However, as soon as my ankle became not flexible enough, I don't pay attention to fashion anymore. Instead, I only wear sportswear nowadays. I think this kind of casual clothes is more comfortable.' These findings supported the theory that health conditions in older women influenced their clothing purchases, and that they may differ from what clothes they actually desire. Health conditions did not depend on the age of participants, rather their mobility largely affected by waist and leg ailments, influenced their clothing choices.

## 5 Conclusion and Implications

The research suggests that the majority of older Chinese women in the study had an obvious change in clothing preferences and dressing habits as they grew older. The study showed change in fashion preferences and dressing requirements in older women, compared to when they were younger. The findings suggest that a large fashion market for older women exists in China through potential consumer feedback. Furthermore, these prominent changes for older Chinese women were categorized into two sections, clothes preference and dressing habit. The differences of clothes preference contained three main aspects, dressing style (from formal style to leisurely style), fit and cut (from fitted cut to casual fit), and colour (from neutral to colorful). For dressing habit, the changes showed in four aspects, which were; conservative to active; self-awareness to share with peers; healthcare-free to healthcare concern; and amount-focused to quality-focused. Based on these summarized features, it is easier to help fashion designers and apparel manufacturers create design points for targeting older female Chinese consumers.

In the research, the common characteristics of fashion consumption for older Chinese women were highlighted as comfort, ease to wear and care, moderate coverage, group preference, and dressing for different occasions. Although some common requirements among these five aspects were mentioned in previous researches [3, 4, 6, 12, 21, 22, 28], they were not integrated with a general concern. However, this result combined fragmented requirements and consideration of influences from individual culture, generation, value conception, and social environment, relating specifically to older Chinese women. These brief focus points would help designers and fashion brands create products that encompass older Chinese women's needs and preferences. The study also presented the differences in fashion consumption for older Chinese women, which were affected by different lifestyles. Their dressing style mainly depended on an individual's working status. A significant difference in dressing preference was shown between women who had jobs, and those who were retired. In the older women's daily lives, the more active they were, the more interested they were in current fashion trends. The importance of fashion depended on family living arrangements, and whether they had female or male offspring. The results showed that these factors about lifestyle were essential to segment the silver fashion market, and target potential customers in the future. Essentially, these key attributes present features that make fashion products desirable to older Chinese women.

The limitation of the research is the number of participants in the qualitative sample. In order to increase the reliability of the result, a larger population is recommended in further research. Drawing or sketches could also be involved in the interview process, and support participants understanding of garment design details. Based on this research, for older Chinese women, designing fashion products that relate to their needs and desires, needs to be further explored.

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# Clothing Custom Design: Qualitative and Anthropometric Data Collection of a Person with Multiple Sclerosis

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**Abstract** Clothes available in the majority of fashion stores are not designed to meet the needs of people with severe physical disabilities. Some companies offer either the service of clothes customization or inclusive clothes to that public. This research was conducted through a case study of a patient with multiple sclerosis to collect qualitative and anthropometric requirements. The data analysis made possible to adapt a pajama to this patient. The study provides evidences on the need for changes in the patterns dimension, so that the user can wear it ergonomically; in the fabric selection to provide thermal comfort to the user; and in the trims selection to confer autonomy in the process of getting dressed.

**Keywords** Assistive technology · Clothing · Data collection · Anthropometry · Multiple sclerosis

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## 1 Introduction

This study is part of the Research and Development for Assistive Technology Network (RPDTA). This network consists of five universities contemplated by the public notice PGPTA CAPES/MCTI 59 [1]: Federal University of Paraná (UFPR), Federal Technological University of Paraná (UTFPR), Federal University of Santa Catarina (UFSC), State University of Santa Catarina (UDESC) and State University of São Paulo (UNESP). The Network focuses on the lack of development of products that take into account the differences and limitations in daily activities of people with disabilities, contributing to the inclusion of this population.

Multiple sclerosis is a disease that, when developed in the body, leads to physical disability patterns. It is characterized as a demyelinating disease, because it causes damage to the myelin that cover nerve fibers that serve the spinal cord, the brain impulses and the optic nerve [2, 3]. The person who has this disease has difficulty in completing daily tasks, requiring customized products that are easy to use. Among the Assistive Technologies used by these people, custom clothing can help them by giving autonomy when getting dressed.

The main objective of this research is to collect data of anthropometric clothing preferences of a person with severe physical disabilities, and compare them with the standard clothing used by people without disabilities in Brazil. The specific objective is the adaptation of a pajama for a person with Multiple Sclerosis using the collected data.

## 2 Methodological Procediments

The characterization of the research was done according to [4]. The research has an applied nature and its approach is qualitative, which means that the data collected is presented and discussed emphasizing their quality without generalized focus to a population, but analyzing a specific case for its in-depth knowledge.

The objectives presented are exploratory, considering that this topic does not present a scientific definition to be explored in order to find a solution regarding the correct way to measure people with severe physical disabilities. The technical procedures lead to a single case study, deeply studying the case of a person with multiple sclerosis through interviews and anthropometric measurement.

The steps for the development of this project are: choice of an individual with severe physical disabilities to develop the case study; interview through a questionnaire with semi-structured questions; anthropometric measurements based on specifications of the [5]; data presentation and its analysis in relation to the researched theory; adaptation of a garment for the individual of the case study.

For this study were used a Term of Free Consent and Informed (TCLE), a protocol relative to preferences for clothing due to physical disability, a protocol for anthropometric measurements (Table 1), a measurement tape for anthropometric measurements, and a camera for data collection registration.

**Table 1** Anthropometric data collected in the case study

| | Measure | Results (cm) |
|---|---|---|
| 01 | Stature | 172 |
| 02 | Head horizontal circumference | 56 |
| 03 | Cross perimeter of the head | 55 |
| 04 | Perimeter of the neck | 39 |
| 05 | Perimeter of the chest | 89 |
| 06 | Waist circumference | 81 |
| 07 | Hip circumference | 90 |
| 08 | Perimeter of the biceps | 26 |
| 09 | Perimeter of the wrist | 16.5 |
| 10 | Arm length | 61 |
| 11 | Length shoulder to shoulder | 35 |
| 12 | Posterior length from waist to neck | 34 |
| 13 | Waist length to floor | 123 |
| 14 | Crotch to floor | 87 |

*Source* From the authors

When starting the research, the caregiver of the subject of the case study signed the consent form in two copies, giving one for researchers and keeping another one for him. The interview was the method used for the application of the questionnaire protocol. The questions were read to the subject of the case study and, as he answered, researchers noted the data. This technique was used due to severe physical disability of the subject.

## 3 Theoretical Foundation

Sometimes clothes do not meet the demands of users, because the sizes of the modeling are not suitable for their body measurements. Fashionable clothes are produced from measurements available in tables, as available in [5–7]. These standard tables did not compute measurements for people with disabilities. Therefore this people need to be measured when they want to purchase customized or tailored clothing, so that it may fit the body.

To collect body measurements it is necessary to note that people with disabilities and without disabilities should be measured in different ways. People with limited movement cannot remain in some positions required during the measurement process, as proposed by [8]. The authors made use of devices to position people with intellectual and motor disabilities in order to collect anthropometric measurements, as they could not stand and stay static. Also, the [9] conducted a survey with 502 people with disabilities using a device to keep them in position, and managed 25 anthropometric measurements of each individual.

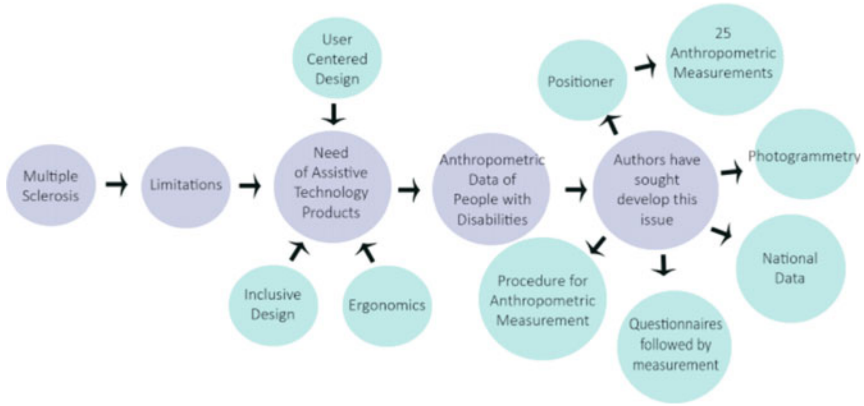


**Fig. 1** Synthesis of the literature review. *Source* From the authors

Steinfeld et al. [10] compiled procedures for anthropometric measurement of people with disabilities, so that designers, consumers, lawyers and politicians, concerned about accessibility, were able to acquire and use the measurements efficiently. Milhomens and Soares [11], Barros and Soares [12, 13] used photogrammetry to collect anthropometric measurements of a sample of people with disabilities, thus showing how to handle and store such data.

Bradtmiller [14] noted the importance of a national survey, so that these measurements can favor the creation of products that promote people's body accommodation. The author suggests that it should start with a questionnaire followed by anthropometric measurements, so that future digital human models can be created to guide product design.

In addition to the anthropometric issue, [15] points out that physical ergonomics expects that products may be adapted to the shapes and dimensions of the users. Silveira [16] highlights that Ergonomics application in garments is used in order to naturally fit the clothing to the anatomical contours of the body, and allow the users to perform activities without restricting them from accomplishing daily tasks. It is an ergonomic garment the one that provides comfort for people with physical disabilities, and autonomy in relation to the caretakers. To summarize the arguments of the theoretical foundation it is presented an infographic in Fig. 1.

## 4 Results and Discussions

Ten questions about preferences for clothing as a result of disability were in the questionnaire. Those were read to the subject and are presented below with their respective answers. The first question refers to accessibility in clothing worn daily by the participant, to whom he pointed out the option: "the clothes have no adaptation, but I wish they had".

Question two refers to the presence or not of the subject with Multiple Sclerosis during the clothing purchase process. To this question, he answered that he did not buy his clothes because this activity was performed by the caregiver.

Question three refers to the way of dressing, for which the participant reported that the caregiver helps him to dress. He argued that he always dresses in lying position, because for him it is easier and faster. Question four addressed the needs, desires and meanings of consumption related to clothing. He said that the most important are the clothes adaptations that facilitate the usage (wear/use/strip) and comfort, especially thermal comfort, to be warm and protected from the wind.

Question five questioned about the size of the clothes he used. It was noted that he used a larger size than that of the body, to facilitate dressing, to move the arms and legs more easily. He criticized that if the clothes had Velcro it would be easier to make this activity.

Question six covers the clothing models in which the subject felt uncomfortable wearing, using and undressing. It was reported discomfort for jeans due to being stuck during the wearing process, because the fabric that does not stretch and muscle tone of the leg that holds the two legs together.

About other types of pants, he said that due to staying at home and not participating in social activities he did not use to wear slacks. He also reported not being able to use capri pants and shorts, because they are short and he must always be covered and warm to not suffer from involuntary movements. That happens because the muscle tone changes with the cold feeling.

Regarding the use of shirts and T-shirts he stated that he only uses long-sleeve shirts, due to the need of maintaining body temperature. Regarding the use of coats, he said he felt discomfort when using overcoats, cardigans, blazers, and jackets with and without hood. As the difficulty of wearing these pieces is considerable enormous, he ends up staying home with the heater on. Regarding the use of underwear, he said that he uses pajamas, but the one with no button is harder to wear.

The seventh question addressed his preference for specific fabrics. The participant said that he prefers cotton, justifying that "they have less possibility of causing allergy". The user also used synthetics fabrics, "I wear a thermal of Kenko Patto that protects and warms the skin and protecting me a lot from the cold weather".

The eighth question addressed the modeling accessories used in clothes and the difficulties related to its use. In relation to regular buttons and pressure buttons, the user affirmed: "I have no strength to handle the button". In relation of magnetic buttons the user said to have never used them, but thought it would have no strength to handle it. Regarding the zipper, he said that "with a larger handle and if it is already engaged, I can use it". He said that Velcro would be the best option for him and that if the pants had Velcro on the sides, it would be easier to use them. He said he did not use eyelets, and almost did not wear shoes.

Elastic is used by the participant and have no complaining. On the other hand, when talking about the pockets he commented that "people with disabilities stay a long time with pajamas and it is important that the blouse have pockets, mainly in the center of it". In relation to cuff blouses, he said: "I think it would be ideal for me to not have to hold the handle of the pajamas with duct tape". About the seams, labels and prints, he proved to be indifferent, saying that they do not cause discomfort.

On question nine, they were presented four figures for the participant, which are the images shown in Fig. 2. The questions were about were concerned about the acceptance to wear this kind of clothes. The participant said he would use all of them. For the first figure he said: "if it was easy to put on and take it off I would use it". For the second figure he said: "it would be great for self-esteem". For the third one he suggested that "it would be great if there was a model like this for pant-shorts". And finally, to the fourth model, he emphasized the necessity to have the zipper already engaged, so that he could dress it by himself.

Finally, it was asked to the caregiver if he had any comment to make about the clothes and the activity of dressing the subject with multiple sclerosis. He then suggested some adjustments to the clothing, which are the following: Application of Velcro in inclusive clothes to give autonomy for PwD; clothes with adjustable sizes; shorts with two side flaps with Velcro to allow the user to fully open it (the same as a diaper with Velcro); back of the blouses open as a hospital gown.

The anthropometric measurements were taken with the subject in a wheelchair without tilt trim, that is, with seat and backrest angle of 90°, but there was a pad on the back of the subject studied, whose thickness was 10 cm, and a separator between the legs of the subject, whose measured was 21 cm. The measures of subject requesting the realization of subtle movements by the participant when necessary, were noted and the results made the photos.

The height measurements and hip could not be measured on the first visit, when the subject was in the wheelchair, due to the fact that small movements, like as raising the arm, causing spasticity in the subject, so the authors chose to not put it on stress, manipulating it, leading to occurrence of this framework. On a second visit, he was lying in bed, the measure of the stature and hip were taken. The anthropometric data are show in Table 1.

As the collection of images, some are shown in Fig. 3 to illustrate the anthropometric measurement procedure performed.


**Fig. 2** Images shows on protocol. *Source* **a** Adapted product with picture available in internet. **b** Company Lado B Moda Inclusiva (http://ladobmodainclusiva.com.br/). **c** Company Lado B Moda Inclusiva (http://ladobmodainclusiva.com.br/). **d** Company AdaptWear (http://www.adaptwear.com.br/)

**Fig. 3** Anthropometric measures. *Source* From the authors

The analysis of the collected anthropometric data was made by the opposition between the recommendations of [5] (Clothing: Reference measurements of the human body, wearability for men with body type, normal, athletic and special) for male anthropometric measurement, and possible procedures to be executed in a person with multiple sclerosis without causing stress (which leads to a spasticity frame) and injuries, as well as without the use of the device to position cited by the [9]. The considerations refer to the 14 proposed measures in this standard.

It is emphasized that the standard refers only male bodies, which are divided into athletic, special and normal. The first term relates to the "male body whose measure is greater than the chest waist circumference" ([5], p. 1), the definition for the second term is the "male body whose waist circumference is greater than the measurement of the chest and general measures are larger than the measurements of average body" ([5], p. 1), the definition for the third term is "male body whose measure chest and waist are equal or very close" ([5], p. 2).

From the measurements obtained and presented in Table 1, it is noted that that the subject has a body classified as "athletic". Regarding the form of measurement of height, it is emphasized that the rule states that this measure refers to the highest point of the head of the foot region and should be taken with the subject in an upright position. As the participant with Multiple Sclerosis was not standing and erect the measure was taken with him lying on a bed at 180° and with legs bent at the knee region, slightly fallen to the left side. For height was added to the measure from head to hip, hip to the knee and knee to heel. The form of measurement has been adapted to the subject's reality and was not taken in the first technical visit, but in a second, in which the subject was in bed, the ideal place to take the measure of what the wheelchair.

The measurement of the horizontal perimeter of the head, the cross-sectional perimeter of the head and neck circumference were achieved exactly as suggested by the standard. To measure the chest followed proposed by the [5], but the subject cannot be naked, because of the occurrence of cold cause spasticity, so the measure was taken on clothes. The waist circumference was measured with the subject seated, the proposed would be that he was standing and upright, but due to the inability took to him as the sitting and dressed, passing the tape between the average level of the lowest rib and the crest upper ilium.

The perimeter of the hip cannot be measured in a first technical visit, a second visit data collection technique was performed when the patient was lying in bed. The body was gently lifted with a crane that belongs to the human research subject, so the tape could through your hip and measured the circumference of it, as set by the standard. The standard establishes the need to take the measurement with the subject standing, which appeared unfeasible for this subject.

The perimeter of the biceps should be taken according to [5], at an angle of 90° between the upper arm and forearm. The measure was taken in the correct position due to the support arm in the wheelchair. Pulse perimeter measure was taken with the man's hand closed, not open as suggested by the standard, due to the involuntary contraction of this member that did not allow it to be opened without causing pain.

According to [5] arm length must be measured with the flexed arm, so the body upright, his right arm down, elbow slightly bent to position the hand in the groin. The measure was taken in approximate position, since the subject was sitting, and the arm was slightly supported in support of the wheelchair arm. The length measurement shoulder to shoulder was measured as required by the standard, but with the subject seated, not standing as suggested.

As the posterior extension of the trunk should be taken with the upright man, but was taken with him sitting in a wheelchair that made this procedure difficult, but as the subject does not have enough support column it is necessary to support the back the chair. Measures starting from the waist to the 7th cervical vertebra, according to the prevision in the norm.

To measure the length of the waist to the ground was the waist measurement taken to the gluteal region, from this to knee, and the knee to the heel, being all taken the side of the body and the man sitting in the wheelchair. This differs widely from the norm, which provides for the measurement with the subject standing and a single measure of the waist to the ground. As the crotch height, according to the norm, it corresponds to the region of the genital area to the area of the foot with the straight man. The measure was taken with the subject in the wheelchair, taking the measurement from the genitals to the knee and this until the end of the heel, and the distance between the legs was given by a foam that the subject uses to keep separate legs (21 cm), since they contract and overlap immediately after its withdrawal.

Realized that the 14 measurements made 10 could not be harvested according to the criteria established by [5] for both a flexible rule for multiple or specific subjects to measure people with limited movement is required. Standards of measures needed try to establish ways to get mathematically to a result plausible for clothes for this people.

The research subject said use number M, however the measurements found with those present along the [5] it was found that among 14 measurements collected six correspond to the size PP, three the size S, three to the size M and 2 the size L. In general, it is emphasized that the biceps measures, wrist, arm, chest and shoulders have to be less developed, fitting into the size PP. The size of the cross head, waist and hip match the size S, height and head correspond to M size, and waist and crotch match the size L.

The variance found between the measurements of the subject makes the transition between different clothing sizes, and the questionnaire preferences for clothing has some needs changing clothes for the subject to be able to use more thermal comfort, security and autonomy. From the incidence of a need for clothing adapted to the subject's need, there was an adaptation of an existing clothing and this was offered to the subject of the case study, so he could use and evaluate the product.

It was acquired a pajama sleeves and long legs of the brand Raio de Sol, in size M, neck model "V" and four front buttons, and using the collected anthropometric measurements and needs identified in the questionnaire to the following changes took place: Cuff insertion into the sleeves of blouse and in the trousers; replacement buttons by Velcro and switch to larger buttons that maintain the aesthetic structure of the clothing, covering the Velcro seam; front side opening in the pants (2 cm forward from the side) and 1.5 cm wide Velcro insertion; the neckline has not changed, due to that has already been acquired in a size that meet the need indicated by the search subject.

The pajamas was the choice clothes for adaptation taking into view is the clothes he wears more and chose to be adapted when asked about it. Figure 4 shows the pajamas with the adjustments made.

**Fig. 4** Adapted pajama (front, back, side detail pants with Velcro, Velcro detail under the buttons of the blouse, cuffs detail in hands and feet). *Source* From the authors

## 5 Conclusions

Making clothes for people with disability is little widespread. One reason for this is the difficulty to obtain anthropometric measurements of these people, and have domain of the method for collecting these data.

This people needs clothes that protect them regarding climatic variation, providing thermal comfort. Clothes adapted to their measures and movements, as well as, easy clothes to dress, facilitating the user's life and providing an independent life, as much as possible.

In this study were evaluated preferences, desires and needs of an individual with multiple sclerosis, which has severe motor disability. Data were collected through questionnaire preferences for clothing, and also through anthropometric measures. The data analysis shows that clothing available in the stores doesn't consider people with severe disability, such as Multiple Sclerosis, because don't have thermal comfort, security and provide autonomy. The anthropometric case study shows that the existing norm [5] is inefficient when applied to people with difficulty to moving, in standing position and in static position.

The case study method applied for a person with Multiple Sclerosis was effective, because it showed possibilities to upgrade the pajama. Adjustments were made and the product was delivered to the user that used it and well evaluate. The offer of a customized product is presented as a social contribution of the article. Starting with this case study the authors want to improve this prototype, make adaptations in other clothing's for people with Multiple Sclerosis and people with other severe disabilities.

The data found contributed to understanding preferences for clothing and anthropometry of people with disability. This search is part of pilot case study that is part of a big project, which aims to contribute to the formation of a protocol for the collection of anthropometric measurements of people with disability, providing the development of Assistive Technology products, as well as production of personalized or inclusive clothing.

The limitations found to conduct this search refers a lack of one device to position severe disability people for taking anthropometric measurements. Besides that, the researches highlight that is important have a nursing or physiotherapy professional during the anthropometric collecting, in order to help in the measurements, providing more security for the search subjects.

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# Part VI
# User Research in Design

# The Form, Senses and Dynamics: A Literature Review on the Philosophical and Technical Coherency for the Development of the Floor-Sitting Furniture Design

**Sani M. Najib and Yusoff B. Saiful**

**Abstract** This paper presents the literature review of the philosophical and technical coherency on the postural behavior for the development of the floor-sitting furniture design. The review encompasses the discussion of space-form, human senses and postural dynamics, and ergonomics relationships to the subject of floor-sitting by citing significant works of scholars among the architects, psychologists and ergonomists that are related to the postural behavior subject. The elaboration of literature contents consists of existing information from cross-disciplinary studies that consequently forms the foundation to the acceleration of research activities, steering for the study of sitting behavior and the development of design within the perimeters of a home environment. The explanations given provide a larger spectrum to the body of knowledge, and lead to further investigations based on the integration of cross-disciplinary studies into other cultural behavior related studies that conceivably contribute to the benefit of researchers and educators at the academia level.

**Keywords** Literature review · Floor-sitting · Postural behavior · Cross-disciplinary studies · Furniture design

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## 1 Introduction

Without a doubt, the floor-sitting behaviors are finely connected to cultural significations. In relation to the development of floor-sitting furniture design, the coherency of philosophical and technical context to the body kinesthesia is immanent as foundation in idea design. This paper explicates the coherency of the integrated context extruded from the key documented works related to the studies of human behavior, which significantly coherent to seating design research. The integration of cross-disciplinary studies is seen necessary when wanting to explore the cultural related studies to uncover new knowledge.

## 2 Literature Review

Forms and behavior have an intricate relationship. The form of an organism or city affects its behavior in the environment, and a particular behavior will produce different results in different environments, or if performed by different forms in the same environment [1].

Stamp [2] in his research outlined 6 contributing fundamental factors that in general affected the body posture/behavior and the architectural experience. Those factors are comprised of the element of scale, texture/materiality, climate/temperature, people/society, weight/resistance, and the configuration of those five elements in the environment. In association to this researcher's design research, these elements manifest according to [3], as the catalysts of memory as well as functioning as encounters, and confrontations to the body which articulate the sensory aspects towards the whole body kinaesthe. In his book The Eyes of The Skin: Architecture and the Senses he adds.

We feel pleasure and protection when the body discovers resonance of space. When experiencing a structure, we unconsciously mimic its configuration with our bones and muscles: The pleasurable animated flow of a piece of music is subconsciously transformed into bodily sensations, the composition of an abstract painting is experienced as tensions in the muscular systems, and the structures of a building are unconsciously imitated and comprehended through the skeletal system. Unknowingly, we perform the task of the column or of the vault with our body.

The sensory experience denoted the body-image theory, which distinguishes the notion of body kinaesthe to the sense of dwelling. Bloomer and Moore [4] in his writing extending [5] propagation on the architectural experience, body and memory integrations, stresses that our body and the movement through the psychoanalytic thought, manifests the haptic and orienting experiences that subsequently fluctuates the feeling of dwelling. It synchronizes the body-image concept through the propagation of the body kinaesthe when confronting the elements of architecture within the dwelling space. He subsequently adds.

All experiences in life, especially experiences of movement and settlement in three-dimensional space, are dependent on the unique form of the ever-present body. It appears that individuals possess an unconscious and changing image of their bodies which is quite separate from what they know objectively and quantifiably about their physicality.

Bachelard [6] in *The Poetics of Reverie*, vindicates these relationships through the polyphony of the senses. He distinguishes the connection of sight and its complementary effects with other perceptual systems harmonizes the body kinaesthe and added, "every touching experience in architecture is multi-sensory". Earlier, the psychologist [5] in The Senses Considered as Perceptual System, asserted this relevancy by propagating the body behavior's articulation through sensory systems when reacted to the types of environment. He added that in order to understand the sensory systems operation one needs to dwell within the particular space, and thus would inspire the engagement of the kinaesthete's experience. Elaborating this concept, and synchronizing this significance is [7] in the paper presented at the Regional Studies Association Annual Conference in Belgium which stated that the dynamics caused by the kinaesthete's experience will consequently leave traces behind, and transform into a locus; a place marked by [personal] history and such body dynamics would repeat concomitantly. This can be seen when one refuge perched at the same spot, or similar section at the space where they occupied for comfort.

In relevance to the technical perspectives, [8] in her review on the ergonomic seating movement adds that one who sits freely tends to cycle their postures over the day [9–11]. She quotes [12, 13] by stating that fixed postures promote more discomfort and chronic disorders and "movement reduces these risks" [14, 15]. When we move or sit freely, "people are usually in constant motion" [10, 16, 17], and "tend to develop unique patterns of seated movements [11, 18]. Linking this, as [19] signified, quoted by [20] the author of the Introduction to Ergonomics, intergrades to the body-link concept aiming to stabilize the open-chain system. For example, while sitting, behaviors such as folding arms, crossing, or flexing the legs can be seen as postural strategies to turn closed chains into approximate open chains that are stabilized by friction for comfort. He adds that a comfort sitting position in a dynamic sense, permits muscular relaxation while stabilizing the open-chain system of body-links. Strengthening that significance to this research concept is ergonomists [21] views on the floor-sitting effects to the body in The Chair: Rethinking Culture, Body, and Design; where according to [22] citing her, such exercise allows "better alignment of the spine than Western-style furniture." He added that when sitting on the floor our body is free to express the body image with movement and variety of positions to cushion for support (see Fig. 1).

**Fig. 1** The utilization of the architecture elements to achieve individual's sitting comfort through various expression of floor-sitting postures, towards the stabilization of the lumbar, thoracic and cervical muscle activity to support the natural *S-curvature* [lumbar lordosis and thoracal kyposis] when perching on the floor

# 3 Results

A floor-sitting furniture prototype based on the floor-sitting behavior was constructed that embodies the connections of the human behavior concept relevancies. The design is based on the signification of the reviewed literatures (Fig. 2).

**Fig. 2** The design of the floor-sitting furniture and its utilization within the home environment

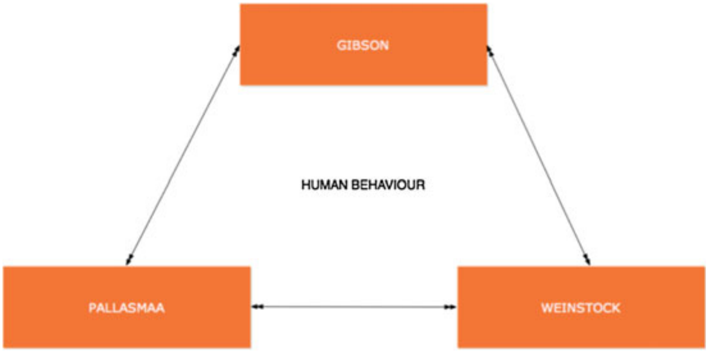


**Fig. 3** The scholar-triangle framework for observing human behavior

## 4 Conclusions

As shown in the literatures, it is important through the incorporation of philosophical and technical signification of human behavior that: (1) Generates the understanding of the phenomenology of the human (floor-sitting) behavior through the articulation of theories propagated by [1, 3, 5] that relevantly indicated a framework of a scholar-triangle for investigating the phenomenon (see Fig. 3). (2) The integration of technical signification established a coherent foundation in diversifying design context. (3) Contribute to the diversity of scholarly knowledge through the demonstration of theories amalgamation in association to the educational research.

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# Design Evaluation of Classroom Armchairs Based on the Anthropometric Measurements of Public Elementary School Students Aged 10–12

**Maebelle Aralar, Lizbeth Mariano, Diana Marie De Silva, Marc Immanuel Isip and Clarissa Pesigan**

**Abstract** In 2007, Department of Education in the Philippines established a standard measurement for classroom furniture. Evaluation of the current and standard classroom furniture, specifically classroom armchair for students aged 10–12 in Rizal, addressed the need to update the established standard. Percent error and the anthropometric measurement of students based on Parcells' (1999) determinant of mismatch for classroom furniture was used to compare the standard and the current classroom measurement. No difference was present between the current and standard measurement. Comparison of the anthropometric measurement and standard measurement showed a three cm mismatch between the popliteal height and seat height as well as the buttock-popliteal and seat depth. Low frequency of students fit the standard measurement. New measurement was recommended with a seat height of 36.10 cm; seat depth of 35.60 cm; and table surface height of 53.90. Higher number of students fits in the new recommended design.

**Keywords** Design · Anthropometrics · School · Furniture · Philippines

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## 1 Introduction

School children spend most of their time in a classroom doing activities like reading, writing, and listening and such activities are supported by classroom furniture like chairs and tables. It is important that a suitable design is considered in the production of classroom furniture. Proper design of classroom furniture helps reduce muscular disorder as well as increases the concentration of students during class [1].

Factors like incorrect posture in early childhood and puberty, heavy school bags and equipment, poor nutrition and lack of physical activity can affect the muscular-skeletal system. In early stages of development appears irregular curves and will cause more problems in the mature years. According to Dr. Smak [2], aged six to twelve is a crucial stage to the health of the spine. Also, at the age of 10–12, there are children who develop body proportions similar to those of an adult [3] and some do not even change [4]. A big variation in body measurements of children are present in this age bracket primarily due to the stage called puberty. That's why it is important to consider the proper design of equipment for children depending on their age bracket.

Studies conducted in Ireland [5], England [6] and United States [7] showed that sitting contributes to around 40–41 % of low back pain in school children caused by sitting. Poorly-designed classroom furniture is also seen as a factor for cases of regular bouts of back, neck and headache pain for many grade school and adolescents. Aside from that, it affects the learning process of students in terms of discomfort that lessens the concentration of students during class. Good furniture results to different learning styles for each student ensuing better concentration, communication and information [8].

Several studies in Southeast Asia confirmed that there were mismatch between the classroom furniture and the different body dimensions of students. A study in Malaysia [1] confirmed a mismatch between the anthropometric body dimensions of Malaysian university students and classroom furniture, same as in Arabic primary and preparatory school for boys [9]. In the Philippines, same study was conducted [10] and results showed that a mismatch between the classroom furniture and anthropometric body dimensions of 13 primary schools in Metro Manila exists in all the grade school levels. Mismatch was found specifically in the popliteal height and seat height, buttock-popliteal length and seat depth, and table height and elbow rest height.

The Department of Education 2010 released a manual that includes standard measurements of classroom chairs, tables, and armchairs based on the anthropometric study conducted by the Bureau of Elementary Education. Even though standard measurements for classroom furniture are already available, the possibility that these standards are not followed is highly probable or not applicable anymore since the standard measurement was established way back 2007. Therefore, design evaluation is necessary to detect possible mismatch between the classroom furniture dimensions and student body dimensions and establishment of new standards in order to prevent improper posture among students and poor school performance.

# 2 Materials and Methods

## 2.1 Materials

For the collection of body measurements, the tools and equipment used are weighing scale, tape measure, big and small anthropometer, adjustable chair, and steel tape. These tools and equipment were used in getting the different body measurements necessary for the design of classroom chairs. Also, a form was used by the measurer for an easier recording of data. For the analysis of data gathered, MiniTab 16 was used.

## 2.2 Sample Size

A total of 200 students, 102 male and 98 female, were considered in this study. Samples were selected using simple random sampling in nine central schools in the province of Rizal, Philippines.

## 2.3 Variables Considered

In regards to the evaluation and design of classroom furniture, 12 body dimensions and three classroom furniture dimensions are being considered and are given below [11]:

(a) *Sitting height*. It is the vertical distance from the surface of the seat to the vertex of the head.
(b) *Sitting elbow height*. It is the vertical distance between the bottom of the elbow and the sitting surface; elbow is in 90° of flexion. This determines the height required for the armrest.
(c) *Sitting shoulder height*. It is the vertical distance between the sitting surface and the students' top of the shoulder at the acromion process. This is needed in determining the upper back rest height.
(d) *Thigh clearance*. It is the vertical distance between the sitting surface and the top of the thigh at its intersection with the abdomen. It is measured using a vernier caliper. Table height will be determined by the thigh clearance, popliteal height and shoe clearance.

(e) *Sitting knee height*. It is the vertical distance between the floor and the uppermost point of the knee.
(f) *Popliteal height*. It is the vertical distance between foot resting surface and the posterior surface of the knee and is measured with 90° knee flexion.
(g) *Stature*. It is the vertical distance between the surface of the floor and the vertex of the head.
(h) *Buttock-popliteal length*. It is the horizontal distance between posterior surface of the buttock and the posterior surface of the knee or popliteal space. The distance is measured from the block to the forward edge of the sitting surface. Buttock-popliteal length is necessary for the seat depth.
(i) *Sitting hip breadth*. It is the maximum horizontal distance across the hips in the sitting position. It is needed for the determination of seat width.
(j) *Body mass*. It is simply the weight of the student.
(k) *Buttock-knee length*. It is the horizontal distance between the most posterior point on the buttocks to the most anterior point on the knee.
(l) *Forearm-hand length*. It is the horizontal distance between the posterior end of the elbow to the longest finger of the hand. When measuring, the upper arm should be at 90° angle with the lower arm.
(m) *Seat depth*. It is the horizontal distance of the sitting surface from the back of the seat where it is assumed that the buttock begins at the front of the seat. It should be deep enough so that the region behind the knees would not hit the front seat.
(n) *Table height*. It is the vertical distance between the floor surface and the top of the front edge of the desk or table.
(o) *Table clearance*. It is the vertical distance between the floor surface and the bottom of the front edge of the desk or table.

## 2.4 Data Analysis

Data gathered were subjected to statistical analysis which includes mean, mode, standard deviation, maximum, minimum, 5th percentile, 50th percentile and 95th percentile. The percentiles determined the percentage data that was considered for each variable.

Pearson correlation was also used to test if there's relationship between the variables needed for the design of classroom furniture. Variables were tested with respect to stature and was interpreted as follows: 0.00–0.19 as very weak, 0.20–0.39 as weak, 0.40–0.59 as moderate, 0.60–0.79 as strong, and 0.80–1.00 as very strong.

Independent t-test was also used in order to determine if male and female body measurements can be combined in order to come up with single design accommodating both. Analysis of variance (ANOVA) was also performed to see if there's a significant difference between male and female students' body measurements considering their age (10, 11, and 12 years old).

Equation (1) was also used to compare if the current measurement follows the standard measurement.

$$percent\ error = \frac{|current - standard|}{standard} \times 100 \tag{1}$$

*Current* stands for the average of current measurement of classroom armchair while *standard* stands for the given standard measurement.

## 2.5 Mismatch Calculation

In order to measure the degree of mismatch between the students' body dimensions and classroom armchairs, the following criteria was used [7]:

*Popliteal Height and Seat Height Mismatch*. A mismatch exist between popliteal height and seat height if the seat height is either >95 or <88 % of the popliteal height.
*Buttock-Popliteal Length and Seat Depth Mismatch*. A mismatch exist between buttock-popliteal length and seat depth if the seat depth is either <80 or >95 % of the buttock-popliteal length. Again, for a stricter definition, a mismatch is present if the seat depth is either <80 or >99 % of the buttock-popliteal length.
*Knee Height and Desk/Table Clearance Mismatch*. A mismatch exist if the desk/table is <2 cm higher that the knee height.
*Elbow Rest Height and Table Height Mismatch*. A mismatch is identified if the table height is below the minimum acceptable table height or above the maximum acceptable table height.

An acceptable elbow rest height is computed using the formula:

$$hE = hEv + U[(1 - \cos\theta) + \cos\theta(1 - \cos\beta)] \tag{2}$$

*hE* is the shoulder flexion and abduction, *hS* is the shoulder height, *hEv* is the vertical elbow height, *U* is the upper arm length (U = hS − hEv), $\theta$ is the shoulder flexion and $\beta$ is the shoulder abduction.

According to Chaffin and Anderson (as cited by Parcells et al. [7]), the minimum and maximum shoulder flexion is 0° and 25° respectively with a corresponding cosines which are 1.00 (0°) and 0.9063 (25°). Also, the minimum and maximum abduction angles are 0° and 20° respectively with corresponding cosines which are 1 and 0.9397.

By substituting the values in Eq. (2), the minimum table height would be $hE = hEv$. On the other hand, the maximum table height would be:

$$hE = 0.8517\,hEv + 0.1483\,hS \tag{3}$$

## 2.6 Standards Computation

In order to compute for the standard measurements of the classroom armchair, the following are general criteria that can be followed [11]:

*Seat height*. The 5th percentile of the popliteal height may be used as the maximum allowable seat height. Shoe heel allowance should also be added which is 0.5 cm.

*Seat depth*. The 5th percentile of the buttock-popliteal length should be used to determine the seat depth.

*Seat width*. The 95th percentile of hip breadth and 15 % allowance for clothing and arm movement is the recommended seat width.

*Seat Back Rest Height (Upper)*. The 5th percentile of the sitting shoulder height is considered for the upper part of the backrest.

*Seat Back Rest Height (Lower)*. The 5th percentile of the sitting elbow height determines the lower part of the back rest.

*Table Surface Height*. For the table surface height, the minimum and maximum table height was considered using Eqs. (4) and (5).

$$\begin{aligned} \textit{Minimum table height} = {} & \textit{seat height} \\ & + \textit{minimum } 5\textit{th percentile of sitting elbow height} \\ & + \textit{shoe heel allowance} \end{aligned} \tag{4}$$

$$\begin{aligned} \textit{Maximum table height} = {} & \textit{seat height} + \textit{functional elbow height} \\ & + \textit{shoe heel allowance} \end{aligned} \tag{5}$$

Functional elbow height is determined using Eq. (2).

*Table surface width*. The recommended table surface width should be 95th percentile of the hip breadth with 15 % allowance for clothing and another 15 % for clearance. For the armchair's table surface width, the value is divided by two.

*Table surface depth*. The 50th percentile or the average design of the forearm-hand length and 50 % allowance should be considered in the design of the table surface depth.

According to Ismaila et al. [11], 5th percentile of the popliteal height is used in order to accommodate larger number of students especially the shorter ones. Also, the 5th percentile of buttock-popliteal length, sitting shoulder height and sitting elbow height is considered for seat depth, upper back rest height and lower back rest height respectively. On the other hand, 95th percentile is considered in designing seat width in order to accommodate larger number of students including a fat student. Allowances necessary for every parameter are also included.

# 3 Results and Discussion

## *3.1 Independent T-Test and ANOVA on Male and Female Body Dimensions*

An independent t-test was conducted for each parameters to determine if the measurements for male and female can be combined. Results showed that only sitting elbow height cannot be combined since the mean of male and female students differ from each other.

After combining the measurements of male and female students, one-way analysis of variance (ANOVA) was performed using Minitab 16 in order to see if there is a significant difference between the body measurements of students aged 10, 11 and 12. Results showed that only the mean sitting elbow height has no significant difference among the of Grade 5 and Grade 6 male and female students aged 10, 11 and 12. The rest showed significant difference which implies that for every age, a different measurement of classroom armchair should be used.

Different design for every age is very costly and impractical that's why age groups/brackets are necessary. In this case, students aged 10–12 are grouped as one for a single design of classroom armchair.

## *3.2 Comparison of the Standard and Current Armchair Design*

Table 1 shows the comparison between the current and standard wooden armchair while Table 2 shows the comparison between the current and standard wood and steel armchair using percent error.

Based on Tables 1 and 2, no significant difference can be found between the current and standard measurement of school armchairs for grade 5 and grade 6 since the accepted percent error for each parameter is less than 10 %. According to Appalachian State University [12], the acceptable percent difference or error is less than 10 %. Possible human error and manufacturing error is present in seat height in Table 2 since percent error is greater than 10 %.

**Table 1** Comparison of the current and standard measurement of wooden armchair using percent error

| Classroom armchair parts | Measurement | | Error |
|---|---|---|---|
| | Current | Standard | |
| Seat height | 40.07 | 40.00 | 0.18 |
| Seat depth | 39.17 | 40.00 | 2.08 |
| Seat width | 46.23 | 43.00 | 7.51 |
| Back leg height | 80.83 | 80.00 | 1.04 |
| Table surface height | 60.50 | 64.00 | 5.47 |
| Table surface width | 23.60 | 25.50 | 7.45 |
| Table surface depth | 60.50 | 62.50 | 3.20 |

**Table 2** Comparison of the current and standard measurement of wooden and steel armchair using percent difference

| Classroom armchair parts | Measurement | | Error |
|---|---|---|---|
| | Current | Standard | |
| Seat height | 42.50 | 38.50 | 10.39 |
| Seat depth | 38.37 | 40.00 | 4.08 |
| Seat width | 43.30 | 43.00 | 0.70 |
| Back leg height | 81.00 | 80.00 | 1.25 |
| Table surface height | 66.27 | 64.00 | 3.54 |
| Table surface width | 25.80 | 25.50 | 1.18 |
| Table surface depth | 61.43 | 62.50 | 1.71 |

### *3.3 Degree of Mismatch Between Anthropometric Measurement of Students and Standard Armchair Measurement*

Computation of the degree of mismatch was performed in three parameters for the design of armchair in order to determine if the standard armchair is fitted for students' use. Table 3 shows the comparison between the standard measurement of armchair and the determinant of mismatch as well as the degree of mismatch.

Based on Table 3, mismatch occurs in the popliteal height and seat height and buttock-popliteal height and seat depth. In terms of knee-height and table clearance, there are no mismatch between the standard measurement and the anthropometric measurement of student. It was obtained by getting the difference of lower surface of table height and the sitting knee height. It can also be observed that the degree of mismatch is not significant. The elbow rest height and table height are not mismatched.

On the other hand, Fig. 1 shows the comparison between the number of students that falls below and above the standard measurement for armchairs. It also shows the number of students that fits the standard.

**Table 3** Parameters, standard measurement and determinant of mismatch for measuring the degree of mismatch between anthropometric measurement of students and school armchair

| Parameters | Standard measurement (cm) | Determinant of mismatch | | Degree of mismatch (cm) |
|---|---|---|---|---|
| | | Criteria | Value (cm) | |
| Popliteal height and seat height | 38.50 | <88 and >95 % of popliteal height | <41.00 and >41.98 | 3.00 |
| Buttock-popliteal height and seat depth | 40.00 | <80 and >95 % of the buttock-popliteal height | <43.40 and >45.40 | 3.40 |
| Knee-height and table clearance | Not given | <2.00 | | No mismatch |
| Elbow rest height and table height (male) | 64.00 | <minimum table height and >maximum table height (based on the 95th percentile) | 62.00–67.07 | No mismatch |
| Elbow rest height and table height (female) | 64.00 | | 63.00–67.89 | No mismatch |

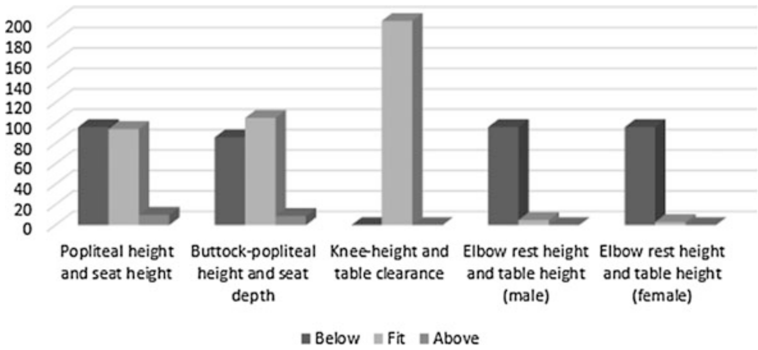


**Fig. 1** Comparison between the number of students that fall below, fit, and above the criteria

## *3.4 Determination of New Standard Measurement for Armchair*

In the materials and methods part, criteria for designing standard measurements for classroom armchair was established. The said criteria aims to consider higher number of students that will fit on the classroom armchair. Shown in Table 4 are the computed set of recommended standard measurement for school armchair of Grade 5 and Grade 6 students.

The recommended measurement accommodates higher number of students compared to the standard measurement in terms of seat height, seat depth, table

**Table 4** Parameters, criteria, and computed recommended standard measurement for grade 5 and grade 6 school armchair

| Parameters | Criteria | Computed recommended standard measurement (cm) | |
|---|---|---|---|
| | | Male | Female |
| Seat height | 5th percentile of the popliteal height + shoe heel allowance of 0.50 cm | 36.10 | 36.10 |
| Seat depth | 5th percentile of the buttock-popliteal length | 35.60 | 35.60 |
| Seat width | 95th percentile of hip breadth + 15 % allowance | 43.44 | 43.44 |
| Seat back rest height (upper) | 5th percentile of sitting shoulder height | 78.10 | 78.10 |
| Seat back rest height (lower) | 5th percentile of the sitting elbow height | 13.00 | 13.00 |
| Table surface height | For the minimum table height, refer to Eq. 3 | 49.60 | 49.60 |
| | For the maximum table height, refer to Eq. 4 | 53.90 | 53.90 |
| Table surface width | (95th percentile of hip breadth + 15 % allowance for clothing + 15 % allowance for clearance)/2 | 22.08 | 22.08 |
| Table surface depth | 50th percentile of the forearm-hand length + 50 % allowance | 59.25 | 59.25 |

surface height and table clearance. On the other hand, since there's a small difference between the standard and recommended measurement in terms of surface width and depth, the standard measurement can still be used.

## 4 Conclusion

Though the standard measurements of classroom armchair followed the general criteria, the frequency of students that fits the standard classroom armchair are very small. Hence, a recommended design was established by following the criteria used by Ismaila et al. [11]. After evaluating the recommended design to the anthropometric measurement of students, results showed that higher frequency of students fit the recommended measurement for classroom armchair compared to the standard measurement. Parameters like seat height, seat depth, seat back rest height, and table surface were changed since it caters larger number of students that are appropriate for their size. On the other hand, seat width, table surface width and table surface depth were maintained since the computed recommended size is not significantly different to the standard measurement.

In conclusion, the newly designed classroom armchair for Grade 5 and Grade 6 accommodates larger number of students than the standard measurement. Therefore, it can provide more students comfort and can lessen the number of students that might experience health-related problems like back pain.

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# An Integrated Analysis of Customer Requirements for Bicycle Leisure Activity Functional Clothing Design

**Ming-Chyuan Lin, Yi-Hsien Lin, Shuo-Fang Liu and Ming-Shi Chen**

**Abstract** The enhancement of our living quality has made people increase requirements of product functions. Bicycle-related clothing is known to play an important role for biking in comfort and safety. Most manufacturers mainly focus on the improvement of material properties of clothes instead of clothing design to meet customer requirements. This shortsighted view may not help increase the marketing competition. The objective of this research is to use an integrated procedure to determine customer requirements for bicycle leisure activity functional clothing design. In this research, a multiple regression analysis on identifying potential customers is used, and followed by the AIO lifestyle questionnaire, factor analysis and conjoint analysis to determine groups of customer preferences for bicycle leisure activity functional clothing design. The preferences of different ethnic group contents will be referenced for designers to define customer requirements and criteria in the process of bicycle leisure activity functional clothing development.

**Keywords** Customer-oriented product design · Bicycle leisure activity functional clothing design · Psychographics · Factor analysis · Conjoint analysis

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## 1 Introduction

Product design is an integrated decision-making process that aims to introduce good products in the market that can appropriately meet the preferential requirements of customers [1]. Biking has become a popular activity due to its contribution in maintaining health. Bicycle-related clothing can play in securing advantages in biking comfort and safety. Currently, the improvement of our social livings has made people to increase their requirements on bicycle leisure activity functional clothing and diversify their preferences in product characteristics. This change makes clothing designers face the pressure of technological integration and tend to use the customer-oriented product design strategy. For designers, an accurate grasp of customer requirements and preferences and design creative products to attract customers is an important factor to promote product development [1, 2].

Therefore, the design of clothing is a complicated task that heavily relies on manufacturing techniques, expert experiences and customer requirements. Customer requirements are even considered as the crucial factor to the success of clothing design. However, most clothing designers and manufacturers usually focus on the improvement of the material properties of clothes instead of recognizing the new market demands, and might design clothing products that cannot meet the customer requirements [3]. As such, the objective of this research is to develop an integrated analysis procedure to determine specific customer requirements for different groups of bicycle leisure activity functional clothing users. The identified customer requirements can be used as an design guidance that help designers link customer requirements with design elements and enhance the design efficiency.

## 2 Development Procedure

Clothing is a cross-disciplinary and technology-integrated article that provides human beings with a basic level of comfort and protection. It covers theories and knowledge of not only physics and chemistry but also sociology, psychology, aesthetics, economics, marketing and anthropology [4]. For designing professional biking clothing, it is important to take physiological functions of human bodies, comfort, cloth functions, aesthetics, maintenance and care, and consumers' lifestyles into comprehensive consideration [5]. As such the research is developed based on user experiences that applies questionnaires, psychographic analysis and statistical factor analysis to identify user group requirement attributes and explore their preferences on leisure activity functional clothing [6]. The conjoint analysis is then proceeded with different clothing characteristic cards to determine the preferences of different customer groups. The framework of the research procedure is divided into three stages: (1) regression analysis for potential customer definition, (2) identification and evaluation of customer requirements, and (3) conjoint analysis for determination of group customer requirements. In the first stage, a general questionnaire regarding personal information and daily consumption behavior was designed and distributed to the experienced users. The research then applied the concept of multiple linear regression analysis to define potential customers. In Stage 2, the research developed an AIO (A: activity; I: interest; O: opinion) lifestyle questionnaire in psychographic analysis associated with statistical factor analysis to help identify candidate customer requirements. The identified customer requirements were categorized by the technique of clustering analysis and evaluated by the analytic hierarchy process (AHP). These categorized customer requirements are forwarded to Stage 3 for the process of conjoint analysis. In conjoint analysis, the optimum design characteristics for bicycle leisure activity functional clothing that adheres to specific user groups of customer requirements are determined.

## 3 Regression Analysis for Potential Customer Definition

To ensure customer requirements of a wide range of customer groups are appropriately identified, and recommended to the bicycle leisure activity functional clothing design, the research developed a regression model to grasp potential customers for further exploration. Based on the concept of consumer behavior, potential customers are those who will purchase specific products based on their specific interests or preferences [7]. The research designed a general questionnaire and distributed to the bicycle users. The questionnaire includes: (1) personal basic information such as habits and attitudes (2) purchase behavior such as consumption lifestyle and preferences and (3) personal biking experience such as bike casual wears. A total of 102 tested subjects, with 91 men and 11 women completed the questionnaire and their responses were stored in the Microsoft Excel database. The research applied the concept of multiple linear regression analysis to the determination of potential customers. The numeric data were forwarded to the statistical software SPSS V14 for a correlation analysis [8]. After a careful examination according to the respective correlation coefficients, the research built a multiple linear regression model by choosing "averaged monthly income", "monthly leisure consumption", "age", "price on owned bicycles" and "number of owned bicycles" as independent variables, and "monthly biking clothing consumption" as dependent variable, respectively, for the identification of bicycle leisure activity functional clothing potential customers. Note that the proposed regression model has an overall correlation coefficient 0.531 which means a certain degree of reliability. The multiple linear equation for determining potential customers of the bicycle leisure activity functional clothing is expressed as:

$$\begin{aligned}
&\text{monthly biking clothing consumption(dollars)} = 13.528 + 102.227\\
&\quad \times (\text{averaged monthly income}) - 42.541\\
&\quad \times (\text{monthly leisure consumption}) + 14.501 \times (\text{age}) + 9.494\\
&\quad \times (\text{price on owned bicycles}) + 0.537 \times (\text{number of owned bicycles}).
\end{aligned} \tag{1}$$

The research will use the regression Eq. (1) as a screening threshold to define the potential customers. According to the feedback of questionnaire from 102 tested subjects, the average pooled assessment value of the monthly biking clothing consumption is about 800. Those tested subjects who have the value of degree of consent for use experience higher than 800 will be considered as potential customers. Note that about 60 of the 102 tested subjects meet the criterion and will be selected for further investigation.

## 4 Identification and Evaluation of Customer Requirements

In the identification process of customer requirements on bicycle leisure activity functional clothing, the research designed an AIO lifestyle questionnaire that involved customer lifestyles, preferences of requirement attributes and purchase behavior [9, 10]. A total of 117 questions related to preferences and attitudes on biking clothing products were designed for this questionnaire in AIO format and distributed to 60 potential customers. This questionnaire used a nine-point scale with points 1, 2, 3,…, 9 correspond to extremely unimportant, very unimportant, unimportant, slightly unimportant, averagely important, slightly important, important and very important, respectively. The results of the AIO questionnaire were forwarded to the statistical factor analysis to help identify customer requirements [8]. In this research, a six-factor cluster, which has 54.53 % of accumulated variance was chosen. According to factor analysis results, the research defined 6 major customer requirements associated with 27 customer requirement attributes. Table 1 illustrates the identified customer requirements incorporating the requirement attributes. The 6 customer requirements and 27 requirement attributes were forwarded to the AHP for evaluating and assigning weights. The use of AHP is to make a paired comparison of the relative importance for the categorized requirements and the corresponding requirement attributes, respectively [11]. In this research, a nine-scaled levels (from 1 to 9) is used for relative importance evaluation. Scores 1, 3, 5, 7 and 9 denote equally important, slightly more important, quite important, very important and absolutely important, respectively. As to scores 2, 4, 6 and 8, they are the middle score between two neighboring levels. Note that the reciprocal value of the above numbers suggested that the latter items are more important than the proceeding one. In the conduction of AHP, a pairwise comparison matrix is generated and the relative weights for each customer requirement and attributes were calculated. Having passed the consistency check, the relative weights for customer requirements and attributes are determined and illustrated in Table 1.

**Table 1** Identification of customer requirements and attributes associated with relative weights

| Category | Category weight | Requirement attribute | Weight |
|---|---|---|---|
| 1. Quality | 0.122 | Washable | 0.039 |
| | | Little shrinkage and deformation | 0.022 |
| | | Durability | 0.021 |
| | | Lint free | 0.020 |
| | | Supper wash | 0.019 |
| 2. Safety and comfort | 0.131 | Good air permeability | 0.073 |
| | | Colors and reflective streaks | 0.058 |
| 3. Appearance | 0.155 | Beautiful style | 0.040 |
| | | Good color combination | 0.038 |
| | | Colorfulness | 0.037 |
| | | Little discoloration | 0.024 |
| | | Good cut | 0.017 |
| 4. Auxiliary function | 0.176 | With pocket | 0.049 |
| | | Activity free | 0.032 |
| | | Light weight | 0.030 |
| | | Easy maintenance | 0.024 |
| | | Fast dry | 0.021 |
| | | Anti-odor | 0.020 |
| 5. Materials | 0.120 | Flexibility | 0.048 |
| | | Velvety touch | 0.043 |
| | | Delicate texture | 0.029 |
| 6. Main function | 0.296 | Insulation | 0.061 |
| | | Sweat relief | 0.057 |
| | | Waterproof | 0.055 |
| | | Windbreak | 0.050 |
| | | Anti-UV | 0.039 |
| | | Wear resistance | 0.036 |

## 5 Conjoint Analysis for Determination of Group Customer Requirements

In Table 1, the overall importance weights of customer requirements and attributes were compared and ranked. The research will use conjoint analysis based on the evaluation of customer requirements and attributes shown in Table 1 to identify preference attribute combination of group bicycle users for the bicycle leisure activity functional clothing design. When dealing with the process of conjoint analysis, the concept of orthogonal array is applied in the experimental design that help efficiently conduct the measurement [12, 13]. The statistical computer software

SPSS V14 is used throughout the proposed research. Considering the size of the orthogonal array in conjoin analysis, customer requirement attributes listed in Table 1 were selected based on their respective importance weights. Table 2 illustrates the determination of customer requirement attributes as well as assigned levels for generating a suitable orthogonal array. Note that the selection of customer requirement attributes shown in Table 2 is based on the consideration of generation of a minimum size of orthogonal array. In Table 2, dummy variables and utility values corresponding to the customer requirement attributes is also defined for further conjoint analysis. The SPSS V14 software helps generate an orthogonal array with a 16 experimental design and will be called as “Card1”, “Card 2”,… and “Card 16”, respectively. Each experimental design consists of one attribute assigned from each customer requirement that constitutes a design alternative of a bicycle leisure activity functional clothing. Table 3 illustrates a list of combined requirement attributes for the 16 experimental design. An example of a combination of customer requirement attributes for Card 1 is illustrated in Table 4.

The research designed 16 cards as a questionnaire and distributed to 45 potential customers [12, 13]. A total of 21 tested subjects completed the questionnaire. In conducting the questionnaire, a preference ranking method is used for 16 cards, with a score of 16 assigned to the card rated as the first preference, a score of 15 for

**Table 2** Representation of 16 experimental design of chosen orthogonal array

| Requirement | Level | Requirement attribute | Virtual variable | Utility value |
|---|---|---|---|---|
| 1. Quality | 1 | Washable | $X_1$ | 1 |
| | 2 | Little shrinkage and deformation | | 0 |
| 2. Safety and comfort | 1 | Good air permeability | $X_2$ | 1 |
| | 2 | Colors and reflective streaks | | 0 |
| 3. Appearance | 1 | Beautiful style | $X_{31}$, $X_{32}$ | 1, 0 |
| | 2 | Good color combination | | 0, 1 |
| | 3 | Colorfulness | | 0, 0 |
| 4. Auxiliary function | 1 | With pocket | $X_{41}$, $X_{42}$ | 1, 0 |
| | 2 | Activity free | | 0, 1 |
| | 3 | Light weight | | 0, 0 |
| 5. Materials | 1 | Flexibility | $X_5$ | 1 |
| | 2 | Velvety touch | | 0 |
| 6. Main function | 1 | Insulation | $X_{61}$, $X_{62}$, $X_{63}$ | 1, 0, 0 |
| | 2 | Sweat relief | | 0, 1, 0 |
| | 3 | Waterproof | | 0, 0, 1 |
| | 4 | Windbreak | | 0, 0, 0 |

**Table 3** Customer requirements and attributes associated with levels and dummy variables

| Card | Combination of requirement attribute | | | | | |
|---|---|---|---|---|---|---|
| Card 1 | Little shrinkage and deformation | Colors and reflective streaks | Colorfulness | Activity free | Velvety touch | Insulation |
| Card 2 | Little shrinkage and deformation | Colors and reflective streaks | Beautiful Style | Light weight | Velvety touch | Windbreak |
| Card 3 | Little shrinkage and deformation | Good air permeability | Colorfulness | With pocket | Velvety touch | Waterproof |
| Card 4 | Washable | Good air permeability | Beautiful style | With pocket | Flexibility | Insulation |
| Card 5 | Little shrinkage and deformation | Colors and reflective streaks | Good color combination | With pocket | Flexibility | Insulation |
| Card 6 | Washable | Good air permeability | Good color combination | Activity free | Velvety touch | Windbreak |
| Card 7 | Washable | Good air permeability | Beautiful style | Light weight | Velvety touch | Insulation |
| Card 8 | Little shrinkage and deformation | Colors and reflective streaks | Beautiful style | With pocket | Flexibility | Windbreak |
| Card 9 | Washable | Good air permeability | Colorfulness | With pocket | Flexibility | Windbreak |
| Card 10 | Little shrinkage and deformation | Good air permeability | Good color combination | Light weight | Flexibility | Waterproof |
| Card 11 | Little shrinkage and deformation | Good air permeability | Beautiful style | Activity free | Flexibility | Sweat relief |
| Card 12 | Washable | Colors and reflective streaks | Good color combination | With pocket | Velvety touch | Sweat relief |
| Card 13 | Washable | Colors and reflective streaks | Beautiful style | With pocket | Velvety touch | Waterproof |
| Card 14 | Little shrinkage and deformation | Good air permeability | Beautiful style | With pocket | Velvety touch | Sweat relief |
| Card 15 | Washable | Colors and reflective streaks | Colorfulness | Light weight | Flexibility | Sweat relief |
| Card 16 | Washable | Colors and reflective streaks | Beautiful style | Activity free | Flexibility | Waterproof |

**Table 4** Representation of customer requirement attributes for card 1

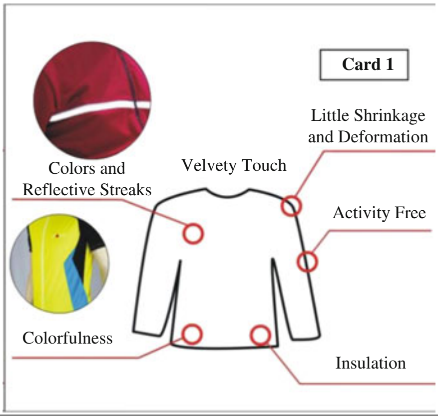
| | Card | Text description |
|---|---|---|
| | Picture description | |
| 1 | The clothing has the following characteristics of customer requirements and attributes: little shrinkage and deformation, colors and reflective streaks, colorfulness, activity free, velvety touch and insulation |   |

**Table 5** Example showing a questionnaire ranking result

| Card No. | Dummy variable | | | | | | | | | | Tested sample 2 Ordinal ranking |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | $X_1$ | $X_2$ | $X_{31}$ | $X_{32}$ | $X_{41}$ | $X_{42}$ | $X_5$ | $X_{61}$ | $X_{62}$ | $X_{63}$ | |
| Card 1 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 1 | 0 | 0 | 9 |
| Card 2 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 8 |
| Card 3 | 0 | 1 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 1 | 10 |
| Card 4 | 1 | 1 | 1 | 0 | 1 | 0 | 1 | 1 | 0 | 0 | 11 |
| Card 5 | 0 | 0 | 0 | 1 | 1 | 0 | 1 | 1 | 0 | 0 | 7 |
| Card 6 | 1 | 1 | 0 | 1 | 0 | 1 | 0 | 0 | 0 | 0 | 12 |
| Card 7 | 1 | 1 | 1 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 13 |
| Card 8 | 0 | 0 | 1 | 0 | 1 | 0 | 1 | 0 | 0 | 0 | 6 |
| Card 9 | 1 | 1 | 0 | 0 | 1 | 0 | 1 | 0 | 0 | 0 | 5 |
| Card 10 | 0 | 1 | 0 | 1 | 0 | 0 | 1 | 0 | 0 | 1 | 4 |
| Card 11 | 0 | 1 | 1 | 0 | 0 | 1 | 1 | 0 | 1 | 0 | 14 |
| Card 12 | 1 | 0 | 0 | 1 | 1 | 0 | 0 | 0 | 1 | 0 | 15 |
| Card 13 | 1 | 0 | 1 | 0 | 1 | 0 | 0 | 0 | 0 | 1 | 3 |
| Card 14 | 0 | 1 | 1 | 0 | 1 | 0 | 0 | 0 | 1 | 0 | 16 |
| Card 15 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 2 |
| Card 16 | 1 | 0 | 1 | 0 | 0 | 1 | 1 | 0 | 0 | 1 | 1 |

the second, and so forth. The least preferred card will receive the score of 1. Table 5 illustrates a tested sample 2 questionnaire ranking result associated with dummy variables and utility values. Having finished the questionnaire, each result of tested subjects is forwarded to the multiple regression analysis, in which the preference ranking score is treated as dependent variable and utility values corresponding to dummy variables are treated as independent variables. A regression equation for the tested sample 2 is expressed as:

$$\mathrm{Y} = 3.20 - 2.07 \times \mathrm{X}_1 + 4.82 \times \mathrm{X}_2 + 3.64 \times \mathrm{X}_{31} + 4.14 \times \mathrm{X}_{32} + 3.52 \times \mathrm{X}_{41} + 3.39 \times \mathrm{X}_{42} - 4.58 \times \mathrm{X}_5 + 2.25 \times \mathrm{X}_{61} + 2.86 \times \mathrm{X}_{62} - 3.25 \times \mathrm{X}_{63} \tag{2}$$

Note that coefficients 3.20 (the constant), −2.07, 4.82, 3.64, 4.14, 3.52, 3.39, −4.58, 2.25, 2.86 and −3.25 in Eq. 2 are the part-worth utility values correspond to the dummy variables. Table 6 illustrates part-worth utility values acquired from the 21 valid questionnaire samples. The 21 part-worth utility values are then forwarded to the K-means cluster analysis of non-hierarchical method to obtain tested subjects' preference groups and figure out which tested subject belongs to which group. According to the results of the K-means cluster analysis, the research divided the tested subjects into three groups. Regression analysis was performed again in which the overall evaluation value of all tested subjects of the same group was treated as dependent variable and the corresponding dummy variables were treated as independent variables. The results for three groups of customers are illustrated in Table 7. Table 8 illustrates part-worth utility values corresponding to customer requirement attributes for group 1 of customers that is based on the result shown in Table 7. Similarly, part-worth utility values corresponding to customer requirement attributes for group 2 and group 3 of customers can also be obtained. Note that distances among customer requirement attributes shown in Table 8 are a simple adjustment to make all part-worth utility values set to be greater than or equal to 0. This adjustment will help clarify and determine the optimum combination of customer requirement attributes for a specific group of customers. Based on the part-worth utility values derived for each customer requirement attribute, the research can recommend optimum combinations of customer requirement attributes for specific group of customers in bicycle leisure activity functional clothing design. Table 9 summarizes the recommendations of optimum combinations of customer requirements for group 1, Group 2 and Group 3 of customers. These three different customer groups have their respective preferences and requirements in the bicycle leisure activity functional clothing design.

**Table 6** Part-worth utility values derived from 21 valid questionnaire samples

| Tested subject | Constant | $C_1$ | $C_2$ | $C_{31}$ | $C_{32}$ | $C_{41}$ | $C_{42}$ | $C_5$ | $C_{61}$ | $C_{62}$ | $C_{63}$ |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Sample 2 | 3.20 | −2.07 | 4.82 | 3.64 | 4.14 | 3.52 | 3.39 | −4.58 | 2.25 | 2.86 | −3.25 |
| Sample 3 | 7.64 | −1.76 | 3.01 | 4.90 | 0.78 | 1.90 | −2.22 | −2.12 | −3.25 | −1.28 | −3 |
| Sample 7 | 8.63 | 1.75 | −4 | 3.51 | 2.51 | −1.87 | −1.74 | −2.04 | −1.25 | 1.49 | 3.25 |
| Sample 8 | 13.27 | 2.10 | −2.35 | −0.95 | −1.2 | 2.17 | −2.45 | −1.192 | −9.25 | −4.55 | −1.5 |
| Sample 9 | 11.26 | −1.89 | −4.86 | −0.35 | −1.47 | 1.03 | 1.78 | 2.88 | −0.75 | −2.28 | −1.25 |
| Sample 12 | 13.32 | −2.07 | −2.43 | −1.12 | −3.37 | −2.37 | −2.87 | −0.54 | −1 | 3.87 | 1 |
| Sample 13 | 9.20 | −0.57 | 4.32 | 3.39 | 1.64 | −3.48 | −2.61 | −4.58 | −0.25 | −4.64 | 3.75 |
| Sample 16 | 2.84 | 3.03 | 0.22 | 0.56 | −3.82 | 0.56 | −0.82 | 2.27 | 6.75 | 2.07 | 5.75 |
| Sample 19 | 8.98 | −0.48 | 3.98 | 0.34 | 2.71 | −5.54 | −1.54 | −1.85 | −1.5 | 3.04 | 2 |
| Sample 20 | 8.46 | 2.54 | 1.46 | −1.7 | −3.33 | −1.08 | 4.42 | 2.31 | −7 | −0.92 | 0.5 |
| Sample 22 | 7.94 | −2.56 | 0.31 | −2.38 | 1.13 | −3.75 | −3.13 | −0.5 | 7.25 | 7.88 | 6.75 |
| Sample 25 | 8.77 | 2.23 | −0.23 | −1.71 | −2.96 | 2.04 | −1.46 | 1.85 | 0.5 | −1.54 | −3.5 |
| Sample 26 | 14.23 | −4.35 | 0.10 | −1.55 | −1.8 | −4.05 | −7.8 | −2.81 | 2.25 | 3.30 | 5.75 |
| Sample 28 | 3.13 | 1.25 | −0.5 | −0.99 | 2.51 | 5.76 | 10.01 | −2.04 | −0.75 | 1.49 | 0.75 |
| Sample 29 | 12.50 | −1.63 | −7.62 | −3.49 | −4.74 | 1.64 | 2.01 | 0.96 | 1.75 | 3.49 | 2 |
| Sample 30 | 9.50 | 3.5 | −1.5 | −5.63 | −1.25 | −2.63 | −3.25 | 6 | 3.5 | 1 | −2 |
| Sample 31 | 13.59 | 0.91 | −0.41 | −6.95 | −4.58 | 2.30 | 2.92 | −0.69 | −3 | −1.92 | −4.25 |
| Sample 38 | 4.73 | 1.65 | −1.9 | 3.70 | 1.70 | 2.83 | 1.45 | −2.8 | 4.75 | −0.20 | −0.25 |
| Sample 41 | 9.78 | −1.78 | 0.78 | 3.06 | 3.06 | −2.82 | −4.19 | −4.23 | 0 | 2.19 | 2.75 |
| Sample 43 | 11.88 | 0.12 | 4.89 | 0.77 | 2.77 | −6.11 | −5.48 | −3.08 | 0 | −1.77 | −3 |
| Sample 45 | 8.39 | 2.36 | −1.86 | 3.04 | −4.21 | 0.54 | −1.21 | −1.15 | −3 | 2.21 | 0.5 |

**Table 7** Example showing part-worth utility values for three groups of customers

| Variable | Group 1 | Group 2 | Group 3 |
|---|---|---|---|
| Constant | 4.67 | 10.89 | 9.63 |
| C11 | −0.24 | 0.95 | −0.34 |
| C2 | 1.36 | −2.27 | 0.67 |
| C31 | 2.82 | −1.73 | 0.10 |
| C32 | 2.28 | −3.21 | 0.36 |
| C41 | 3.50 | 1.23 | −3.20 |
| C42 | 3.16 | 0.86 | −3.34 |
| C5 | −2.88 | 0.71 | −1.14 |
| C61 | 0.75 | −2.96 | 1.58 |
| C62 | 0.72 | −0.79 | 1.84 |
| C63 | −1.44 | −1.07 | 2.60 |

**Table 8** Part-worth utility values corresponding to customer requirement attributes for group 1 customers

| Requirement | Level | Requirement attribute | Part-worth utility value | Distance among requirement attributes |
|---|---|---|---|---|
| 1. Quality | 1 | Washable | −0.24 | 0 |
| | 2 | Little shrinkage and deformation | 0 | 0.24 |
| 2. Safety and comfort | 1 | Good air permeability | 1.36 | 1.36 |
| | 2 | Colors and reflective streaks | 0 | 0 |
| 3. Appearance | 1 | Beautiful style | 2.82 | 2.82 |
| | 2 | Good color combination | 2.28 | 2.28 |
| | 3 | Colorfulness | 0 | 0 |
| 4. Auxiliary function | 1 | With pocket | 3.50 | 3.50 |
| | 2 | Activity free | 3.16 | 3.16 |
| | 3 | Light weight | 0 | 0 |
| 5. Materials | 1 | Flexibility | −2.88 | −2.88 |
| | 2 | Velvety touch | 0 | 0 |
| 6. Main function | 1 | Insulation | 0.75 | 0.75 |
| | 2 | Sweat relief | 0.72 | 0.72 |
| | 3 | Waterproof | −1.44 | −1.44 |
| | 4 | Windbreak | 0 | 0 |

**Table 9** Recommendation of customer requirements for three groups of users

| Customer requirements recommended for group 1 of customers | | | | | | Overall part-worth |
|---|---|---|---|---|---|---|
| Washable | Good air permeability | Beautiful style | With pocket | Velvety touch | Insulation | 8.43 |
| Washable | Good air permeability | Beautiful style | With pocket | Velvety touch | Sweat relief | 8.39 |
| Little shrinkage and deformation | Good air permeability | Beautiful style | With pocket | Velvety touch | Insulation | 8.19 |
| **Customer requirements recommended for group 2 of customers** | | | | | | **Overall part-worth** |
| Washable | Colors and reflective streaks | Colorfulness | With pocket | Flexibility | Windbreak | 2.89 |
| Washable | Colors and reflective streaks | Colorfulness | Activity free | Flexibility | Windbreak | 2.52 |
| Washable | Colors and reflective streaks | Colorfulness | With pocket | Velvety touch | Windbreak | 2.18 |
| **Customer requirements recommended for group 3 of customers** | | | | | | **Overall part-worth** |
| Little shrinkage and deformation | Good air permeability | Good color combination | Light weight | Velvety touch | Waterproof | 3.63 |
| Little shrinkage and deformation | Good air permeability | Beautiful style | Light weight | Velvety touch | Waterproof | 3.36 |
| Washable | Good air permeability | Good color combination | Light weight | Velvety touch | Waterproof | 3.28 |

## 6 Conclusion

Product design is a hybrid activity that requires the integration of designers' knowledge, experience and opinions to ensure the design quality and effectiveness. Currently, the concept of user-centered design becomes popular. The customer-oriented product design strategy will be the key to the success in competitive market. Since the progress of technology has made consumers increase their requirements of product functions. Different groups of customers may have different preferences on product characteristics. As such the designer needs to realize the requirements and preferences of customers to ensure successful product development. This research aims to explore the customer requirements of different groups of customers on bicycle leisure activity functional clothing. The research used multiple regression analysis to define potential customers and the corresponding clothing requirements. The concept of conjoint analysis is also used to investigate the customer requirements of different groups. In this research, the tested subjects can be divided into three groups according to the results of the study. The first group belongs to aesthetic and easygoing importance to the additional functionality and appearance of the bicycle leisure clothing. The second group emphasizes on the quality of materials and additional features of sewing. As to the third group, it tends to the main function of the sewing, security and comfort. It is expected that the research results regarding customer requirements will help designers define design criteria for the development of bicycle leisure activity functional clothing.

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# The Assessment of QFD Applying to Curling Iron of the Hair Salon

**Hsiu-Ching Lu and Fong-Gong Wu**

**Abstract** Despite the booming of the hair salon bringing a wide variety of hair design technology and tools; however, the innovative hand tools bring some problems, such as radio-ulnar clubhand due to the overuse of hands and wrong exertion, envolving occupational injury and the danger of use. The issue of occupational injury occurs with the development of every industry. At first, researches use Observational Method to understand the operational behavior and job requirements; using QFD to assess the design of the curing iron in the market is the most corresponding to the job requirements. The design of the curing iron for hair salon faces too many requirements in the market, so it produces special shapes for the hair style or for the convenience of using handles; however, these changes can't improve the problem of customers burned and the operation of hands. In addition, The bad hand tool design can affect the force of the hands' muscles, using for a long time will cause the tire of muscles and wrists, easily causing disease of muscles and bones, forming occupational injury further. The results of this study can reduce occupational injuries generation hair stylist hand. The results of this study can reduce the incidence of occupational injuries hairstylist hand, and provide design assessment.

**Keywords** Wrist injury · Visual ergonomic · Cognitive ergonomics · Active learning · Occupational disease

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# 1 Introduction

According to the data of Taiwan Bureau of Labor Statistics, there are more than 50,000 workers were employed at the beauty salon or barber shop hairdressers and barbers (Taiwan Comptroller Office 2015). Although the total number of hair-dressers is limited, compare the incidence of work in January 2003 and June 2006 (Taiwan Occupational Safety and Health Association 2015) among other industry groups, accounting for the hairdressing industry compensation cases related to hand wrist rate of about 24 %. In addition, the number of such insurance claims every year since 1998, from the increase in women's beauty and related industries, the majority of musculoskeletal disorders of the situation. Poor posture and manner of operation, such as hair combing, washing and drying must be eliminated to minimize the barber (DOL risk injured New Zealand [1]). Few studies have focused on the neck/shoulder problems hairdresser (Hagberg [2]). Biomechanics workload (2008) quantitative analysis of women's neck and shoulder area hairdresser before and after the intervention. Intensive operations risk frequent mechanical barber is still limited, although bring a variety of hair styling salon techniques and tools, but users still flourish, involving injuries and dangerous to use.

# 2 Cumulative Trauma

Work-related diseases are multi-factorial, where the work environment and the performance of work contribute significantly to the causation of the diseases (World Health Organization (WHO) 1985). Salon staff is highly reusable hand Work-related musculoskeletal disorders are also known as Cumulative Trauma Disorder (CTD), Repetitive Strain Injury or Occupational Overuse Syndrome. The disorders primarily affect muscles, tendons, ligaments, nerves and small blood vessels. Specific work-related activities associated with these disorders include repetitive or forceful exertions. According to Cal/OSHA [3], CTDs may occur from a single micro-trauma or from the build-up of tissue damage from many small injuries; they differ in symptoms and severity from individual to individual even though their work tasks or other activities are similar, and may take weeks, months or years to develop (Table 1).

## *2.1 Curling Use of Observation*

Through the use of behavior we can understand from the work body movements and hand tool operation Limb movement and member needs to make the relationship between.

**Table 1** Scholars discuss hairdressing industry for occupational injuries

| | Contents description |
|---|---|
| (Aghazadeh and Mital [6]) | In the USA for instance over 260,000 hand tool injuries per year have been reported to occur and it is believed that worker–tool mismatches have contributed to these injuries to a significant extent [6] |
| (Konz and Johnson [7]) | Stress can cause trauma disorders such as repetitive motion injuries (RMI). A common RMI symptom reported today is carpal tunnel syndrome (CTS). CTS also has been labeled occupational overuse syndrome or repetitive strain [3] |
| (Storti [10]) | This compression occurs when the size of the tunnel is reduced by wrist deviation of the finger flexor tendons, which also pass through this area [3]<br>Storti [10] reported that bending the wrist forward 90? (acute volar flexion) resulted in a significant increase in pressure in the median nerve in the wrist [3] |
| (Konz and Mital [9]) | To suggest guidelines for preventing and alleviating the symptoms associated with CTS in the design of hand tools. Four broad categories were listed as follows: frequency(reduce the number of cycles for a specific wrist), joint angle (keep the wrist in the neutral position), force (reduce the amount of force and its duration) and non-ergonomic (medical) [3] |
| (Kang et al. [8]) | Examined 221 UK females with upper-limb soft-tissue disorders seeking treatment at orthopedic clinics and identified that hairdressers have significantly more shoulder and ganglia injuries than other occupations. Examined 221 UK females with upper-limb soft-tissue disorders seeking treatment at orthopedic clinics and identified that hairdressers have significantly more shoulder and ganglia injuries than other occupations |
| (New Zealand DOL [1]) | Introduction Musculoskeletal discomfort, pain or injury among hairdressers and barbers is common and results in reduced job performance and productivity, increased time off work, and even early retirement examined 221 UK females with upper-limb soft-tissue disorders seeking treatment at orthopedic clinics and identified that hairdressers have significantly more shoulder and ganglia injuries than other occupations |

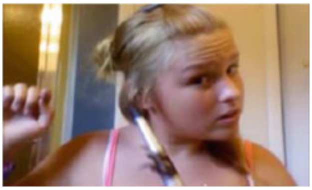
**Table 2** Scholars discuss hairdressing industry for occupational injuries

| Operating | Contents description |
|---|---|
| Power | Buttons to control the temperature warming |
| Comb the whole | Hair partition. Comb the whole |
| Curls | When pressed with the thumb control to take hair clip song hair. Keep hands smooth hair Wait average temperature heat. Hands clasped and require careful and hand burns guests |
| Stereotypes | Hand movements required to maintain parallel, the average wait for hair remember not to bend the heat, you can make the trip after heating |

## 2.2 Use Current Situation Related Curlers

In recent years, it often can be learned for electric hair curling injury case from newspapers and magazines and in the news at home and abroad for curling condition shown in Table 2 using the flashlight to use the current situation at home and abroad, we can learn that in 2012 began on flashlight use, related problems have surfaced, which you can understand the current status of the use of flashlight (Table 3).

**Table 3** Status of domestic and flashlight use

| Occurred case | News footage | Contents description |
|---|---|---|
| 2012 transit news footage |  http://news.tvbs.com.tw/old-news.html?nid=37543 | Cheek caused by improper use of second degree burns |
| 2012 Eastern television news pictures |  http://www.ettoday.net/news/20120216/25289.htm | Use curling falling guests feet caused third-degree burns |
| 2013 youtube WBI error screen |  https://www.youtube.com/watch?v=NQMX7AII5bA | Burning my hair off (hair tutorial gone wrong) |
| 2014 FTV news footage |  https://www.youtube.com/watch? | Use flashlight volumes before they can cause burns forehead |

# 3 Research Method

## 3.1 Preliminary Study

Preliminary study was conducted by a direct observation to the actual use of the existing Electric roller parses. Preliminary study was conducted by a direct observation to the actual use of the existing Electric roller parses. The interviews were conducted to know in general how customers respond to the existing Electric roller parses on the market today as well as the characteristics of the customers towards the desired Electric roller parses in the future. The interview is a preliminary stage that serves as a reference in designing the research questionnaire. It is also a method to get an initial picture of consumer expectations for designing an ergonomic [4].

## 3.2 QFD Work Program

The collected survey questionnaires were tested for their validity and reliability using SPSS software V.22. Then, the collected data were processed using QFD design through House of Quality (HoQ).

QFD (Quality Function Deployment, QFD) quality control by the Japanese master Yoji Akao (Yoji Akao) and important quality control theory, proposed Shigeru Mizuno (Shigeru Mizuno). QFD including the "quality" and "function" and "expand the" three parts. "Quality" is the quality of the house to be achieved by the quality requirements; function, also known function, that is, after listening to customers functions aggregated demand, also appellation customer demand; "expand" that is, to achieve a series of product quality carried out by the process integration, including conceptual propose, design, manufacture and service processes. In other words, quality function deployment that is in the understanding of customer needs, launched a series of process improvement and integration to achieve customer requirements complete quality management capabilities of the product (Kang et al. [5]). The research process is as follows:

(1) Consolidation of domestic and foreign news and Internet usage related flashlight and search method using Quality Function Deployment (QFD) to explore issues related to the operation of the design as a research base.
(2) The status of industry research, and then use flashlight-like conditions and prepare expert questionnaire design.
(3) Expand through Quality Function (QFD) to establish expert co-card score, based on the weight of the resulting correlation between identify design requirements and needs, and then complete the facets assessment.
(4) Based on the above analysis, the US Power Generation Curling designs its conclusions and recommendations.

### *3.3 Quality House*

Quality housing composition is divided into six parts, namel y customer demand, needs assessment, technology needs, relationship matrix, the matrix technology needs connected with technical objectives, the main focus of this study is to establish customer needs and technology needs, and correlation matrix, and use this The results of the use of commercially available hair electric rods assessment.

## 4 Basic Data Analysis

Research in the field visits and interviews with experts in such manner, as the assessment of future questionnaire prepared based on the implementation of the questionnaire obtained as a result of the correlation matrix of the quality of housing needs and technical requirements of the customer, to achieve the multi-faceted assessment criteria to invite more than 10 years Experts: Iraq and thoughts Architects Wei Po Shan hair designers and fashion designers in Milan and even the average consumer to Juan Equality, as the right products and customer needs assessment reconstructed surface.

### *4.1 Implementation Questionnaire*

Through a questionnaire issued more than six years, a senior designer and implementation, respectively (1) Easy to operate (2) Modeling quickly (3) Versatility (4) Security (5) The degree of damage to the hair (6) Appearance (7) Easy to buy

| | | | | |
|---|---|---|---|---|
| 1. Easy to operate | 1 | 2 | 3 | 4 |
| 2. Rapid modeling | 1 | 2 | 3 | 4 |
| 3. Versatility | 1 | 2 | 3 | 4 |
| 4. Security | 1 | 2 | 3 | 4 |
| 5. reduce the degree of damage to the hair | 1 | 2 | 3 | 4 |
| 6. appearance | 1 | 2 | 3 | 4 |
| 7. easy to buy | 1 | 2 | 3 | 4 |
| 8. Affordable | 1 | 2 | 3 | 4 |
| 9. Durable | 1 | 2 | 3 | 4 |

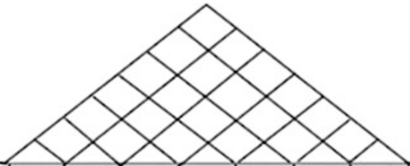
**Fig. 1** Users feel scale

and affordable (8) Durable (9), and where versatility, good looks, easy to buy sex and; therefore, are less than significant removed therefrom after understanding that:. Because of a lot of experienced designers face daily the number of visitors, versatility and good looks to work to help structure the face of relatively little so designers do not pay attention; in addition it is easy to buy the goods directly to the store vendor sales, and therefore is not considered likely to purchase facet.

Do you think an ideal flashlight, its importance conditions required of why? (1–5 min, most important, 5 being most important) (Fig. 1).

**Fig. 2** Consumer demand for quality housing facets of the establishment

$$H_i = \sum_{i=1}^{m} k_i r_{ij}$$



| Quality factors(1) / Customer needs(1) | Importance | Temperature adjustment | Rotating mechanism | Handle design | Retractable mechanism | Exterior design | Cost Control | material | | |
|---|---|---|---|---|---|---|---|---|---|---|
| Customer needs | 5 | 6 | 4 | 9 | 8 | | | 5 | | |
| Easy to operate | 5 | 7 | 2 | 3 | 6 | | | | | |
| Operating speed | 4 | 9 | 1 | 4 | 2 | 6 | 4 | 7 | | |
| Damage to the hair | 3 | 9 | 1 | | 2 | | | | | |
| fair price | 2 | 7 | 4 | 5 | 3 | 2 | 8 | | | |
| durable | 4 | | 8 | 6 | 9 | | 7 | 8 | | |
| | | Safety insulation | Convenient rotation | Roman type Modem and slip | Pressure effort | Nice, suitable for different consumer | Within 1000 yuan | Slip, lightweight, anti-scald | | |
| Engineering importance(h | | 149 | 81 | 115 | 129 | 30 | 68 | 85 | | |

**Fig. 3** Consumer demand for quality housing facets of the establishment

### 4.2 Notary Expertise Tripartite Index Weight Rating

In this study, more than 10 years through product designers, hair stylists and consumers is a weighted score results are as follows (Fig. 3 consumer demand for the establishment of housing quality). From the relationship matrix (Fig. 2. Engineering Measures the indicators and their importance h) formula are explained, as well as other relationships recommendations 1.3.5.7.9 level (or even intermediate values). H, the more important work measures weight.

## 5 Conclusion

(1) Can be seen from the quality of the house, for a professional salon staff, the most important factor for ease of operation and rapid modeling, and corresponds to the technical level of safety as well as to adjust the temperature of effort retractable mechanism design, because different to the general consumer, professional workers themselves to the operation more emphasis on practicality flashlight, allowing its fast and efficient work done.

(2) Results for the quality of the house of the future will find several more orderly market, the results of this flashlight, given the subject's operating, pick out design elements in line with the target product, and evaluated again.

(3) Table 4 can be learned through human factors design principles and the new proposal analysis, proposal shown in the following table.

**Table 4** User operation analysis

| Human factors and principles | Electric hair stick/problem | The new design proposal |
|---|---|---|
| To maintain the integrity wrist | Interference hairstyle needs and wires, causing serious problems ulnar | Wireless charging design, try to make the hand to maintain integrity, reduce ulnar problem |
| Avoid organizations oppression | Member organizations oppression caused by long-term operation | The average reduction in the force member organizations oppression |
| Avoid repeated finger movements | Finger repeat action, does not meet the person who | Reduce repetitive finger and wrist movement |
| Design should emphasize safety | Often hot to the cheeks, ears, fingers of experience | Overheat protection audible alert |
| Do not ignore the left-handed women | Right long operation, causing pain | Let the left auxiliary right weight and effort to alleviate |
| Message simple | Screen display temperature | Temperature Tip |

### *5.1 Notary Expertise Tripartite Index Weight Rating*

See Table 4.

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# Analysis and Research on the Gesture-Based Interaction of Touch-Screen Smartphones for the Elderly Based on Ergonomics

**Yulin Zhao and Delai Men**

**Abstract** With gradual changes in the communication means of people by touch-screen phones, the elderly also need to enjoy better communication services brought by the technological development. Touch-screen phones represent the future trends of mobile handsets. As the main mode of interaction, gestures play an important role in improving the user experience of the elderly. This paper intends to research the operational effects and differences between the elderly in operating touch-screen phones with different carrying platforms. It makes full use of the principles of ergonomics to conduct comprehensive and systematic designs, so as to determine the design approach most suitable for the elderly to operate gesture-based interaction in touch-screen phones to make them feel friendly, comfortable and pleasant and produce good emotional experiences.

**Keywords** Ergonomics · The elderly · Touch-screen phones · Gesture-based interaction

## 1 Introduction

With the rapid development of modern information technology, the tendency that smartphone replaces traditional feature phone seems hard to stop. Due to the population aging of China, the resulted strong demand of the elderly for smartphones and the growth cannot be underestimated. As the newly arisen interactive mode of smartphone, gesture interaction possesses natural, intuitive, portable, direct and integrate advantages. The application of gesture make old people get rid of

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bondage about buttons and complete the operation in a more natural interactive mode, which not only improves the interface usability of mobile phone for the elderly but also make the process of utilizing mobile phone become more quick, efficient and enjoyable. However, according to the deep understanding of the gesture-based interaction design of touch-screen phones in China, most touch-screen phones fail to take into consideration the physiological characteristics of the elderly, thus resulting in a lot of poor designs and experiences. Gesture design for the elderly should carefully refer to the ergonomics corresponding to fingers to provide scientific and theoretical bases for gesture design, hereby increasing the comfort and usability.

In terms of the theory of ergonomics, both finger length and palm width of the elderly are different. Therefore, it should be avoided to blindly utilize the standardized codes in designing gestures. It is necessary to measure the physiological indexes of the elderly. Moreover, the hand holding stability and operational ranges may vary between elderly users and young users. Therefore, we should draw moderate lessons from mature researches on gesture-based interaction and make adjustment in accordance with physiological characteristics of the elderly.

This study proceeds from the perspective of ergonomics. It conducts quantitative and qualitative researches on the operational modes of the elderly to operate touch-screen phones, finger structures of the elderly, flexibility and use frequency of the various gesture combinations, areas covered by hands and operating habits of fingers and then makes a summary. It provides a valid data for the consideration of gesture-based interaction in touch-screen phones for the elderly and interface design in the app development of touch-screen phones for the elderly.

# 2 The Related Concept of the Gesture-Based Interaction Between the Aged and the Intelligent Touch Screen Mobile Phones

## 2.1 *Aging Related Concepts*

According to the international definition, the persons over the age of 65 are identified as the aged. In China, the aged are those over 60 years old. With the progressively aging tend of population, there are more and more old people in China, and so is their proportion of population. In 2010, the aged population took an 8.9 % percentage of the total population in China; in 2011, that percentage reached to 9.1 %; by 2012, it has climbed up to 9.4 %. With the increasing quantity, the old people have to be faced with the severe challenges from several social issues, such as aged-supporting after retirement, medical insurance and support from their children.

## 2.2 Development of the Intelligent Touch Screen Mobile Phones for the Aged

In China, the proportion of the aged population is higher and higher along with the improvement of health conditions, extension of life span and the declining birth rate. Simultaneously, since 3G intelligent touch screen mobile phones started to be popular in 2011, the production cost has been continuously reduced. The prices of the intelligent mobile phones produced by many domestic manufacturers are so favorable that a lot of old persons are attracted to use intelligent mobile phones. In addition, because of the relatively richer experiences on using intelligent mobile phones, many old persons tend to change their present mobile phones. For this reason, the potential market in this field is rather huge. Some investigation indicates that the aged in the new time much more prefer outside social contact and traveling, and much more concerned about their health situation. Besides the basic telephone conversation with the relatives and friends, the aged are also desire for their own social platform, E-shop and entertainment platforms for old people just like what the young people have. Compared with feature phones, the user-friendly interfaces

**Table 1** Analysis of the characteristics of several intelligent mobile phones in China

| Model | Homepage | Feature | Price (CNY) |
|---|---|---|---|
| ZTE D&M |  | It’s Large arc brings a comfortable feel, and the overall design of this mobile phones is very fashionable. It has the large buttons, large font, and one-click dial. And you can use multiple large magnifying glass, solve the problem of old people can’t read | 1399 |
| Cappuccino II |  | The Smartphone of Cappuccino claims to be China’s first brand of smartphones in the elderly, it Designed for traffic security features have been added to prevent mindless consumption of Older Persons. The most special is that it launched the elderly health column, to facilitate the understanding of health information in the elderly | 999 |
| Thimfone F1 |  | The main that entertainment functions of the elderly. The mobile phone interface background interface using wood texture and that meet the cognitive psychology of the elderly | 1999 |
| MC002C |  | This smartphone increase the affection of Remote Assistance feature, it can let the children to assist their parents operation the phone. Besides, MC002C Service for the old custom of light reading that enrich the spiritual life of the elderly | 399 |

of intelligent mobile phones fit better with the users' characteristics on behaviors and cognition, and the same with old users.

Touch-screen phones is widely used for the user and provides the real way of Human-Computer Interface, The elements in the mobile phone interface, such as shift, sliding, rotation and transitions, are more in line with the movement of objects, this interaction is not only suitable for ordinary user groups and is for the elderly. Compared to the ordinary user groups, the elderly population needs more use the products of Touch-screen, because of the touch-screen can compensate for the cognitive deficits in the elderly. At the same time, the large size of the screen can also compensate for the visual decline and the high probability of eye diseases of elderly, so that making mobile phones to better work. Elderly people using the smart phones not only to help the operation for themselves, and elderly people using smart phones can bring pleasure to their daily lives, at the same time, the smart phone can increasing the exchanges with their nieces and nephews, relieve the risk of disease in the elderly, and reduce the financial burden on the state and children of the burden of providing for the aged. The following are the several more typical elderly smart phone of China (Table 1).

## 2.3 The Gesture-Based Interaction of Intelligent Touch Screen Mobile Phones

**The gesture-based interaction to the intelligent touch screen mobile phones** Gestures contain plenty of interactive information and also fit with people's cognition habits. During the human development in the past thousands of years, a number of universal gestures have been created. A simple gesture is usually including the complex information. And it is very natural for people to reflect their intentions with gestures. The gesture-based interaction is capable to realize the smooth transition from the human's cognition space to the computer's calculation space and in consequence effectively ease the "cognition conflict" between humans and computers. With the improvement of the computing power and the performance of interaction devices, it becomes possible to apply the gestures to the field of human-computer interactions.

Previously, the gesture-based interactions were largely realized by touch pens. But actually touch pens are not the real gesture interaction. For the part of the users' operation, it is rather inconvenient to use a pen on a mobile device.

Now mobile devices are increasingly applied in various occasions, while the application of a touch pen requests the precise touches which are rather hard to be realized in a moving situation. In addition, with a touch pen both two hands are needed for the device operation, which is obviously unreasonable. The gesture interaction inevitably tends to be apart from the pen and given back to "hand". The operation is finished by the original living experiences of humans and hands, which will make the operation to be easier and more acceptable.

The development and application of the multi-touch screen technology create some more design spaces and the broader development future, and make the gesture-based interaction to be the inexorable development trend of the human-computer interface interaction of an intelligent touch screen mobile phones.

**Classification of gesture interaction**
First of all, according to the form of classification, can be divided into simple and complex gestures, core gestures, general gestures and so on. Secondly, according to the operation classification, can be divided into Navigation Actions, Object-Related Actions and Drawing Actions.

**Characteristics of gesture interaction**
First is inexact. Based on gesture interaction with non accuracy, a gesture often do not require strict geometry or pressure threshold, gesture recognition is through a feature based or fuzzy extraction method; Second is continuity. Gesture interaction is not a kind of the interaction with based on discrete event location and geometry. The pressure of transformation is continuous, no obvious interval interaction between tasks; Third is instantaneity. Time is a very important factor in gesture interaction, gesture input and Recognition is related with time, in different time and context, there are different interpretations of the gesture, so the gesture based interaction with real-time; Fourth is multi-channel. Starting from the perspective of cognitive psychology, gesture interaction in pressure, position and vision He belongs to the category of interactive channel, so multi channel is one of the most important characteristics of gesture interaction. Fifth is mixed analysis. From the formal point of view, the essence of gesture interactive form based on a mixed. The system, including both the events of discrete and the change of the continuous.

**Advantages of gesture interaction**
First is natural. Gesture is the natural form of human communication, and based on the experience of life, is an easy to understand and Lenovo, learning means of human-computer interaction and low cost; Second is concise and rich. A single gesture can be simply expressed as a command, and continuous hand The hand and fingers in the potential posture and motion state provide rich information for understanding the higher level and gestures, but also effectively reduces the interaction steps, help the user to quickly complete the task; Third is directly. In hand as the input of computer, communication between man and machine will no longer need for intermediate media, users can define a proper hand gesture to control around the human-computer interaction system.

In summary, gesture interactive human-computer interaction provides the way of a more natural and more closely to the interface.

# 3 The Experimental Analysis of Human-Computer Engineering and the Gesture Interaction of the Elders' Intelligent Touch Screen Mobile Phones

From some investigations in the gesture interaction design situation of the touch screen mobile phones in China, we can see the gesture interactions are mostly designed according to the foreign data. The foreign design principles of mobile phones and system APP are directly taken to use without further research or discussion. A lot of bad designs and experiences were caused by the lack of consideration on the features and culture related with Chinese old people.

With the respect of the touch screen mobile phones for the old people, the writer quantitatively and qualitatively carried out the research and concluded on the operation methods, the distribution and classification of hand sizes, the flexibility and operating frequency of various gesture combinations and the experiment analysis in an experimental way. For the experiments, strict criterion was executed for the selection of the research objects by the old user's research group. An experience in using the touch screen mobile phones was requested to be over 3 years which can represent the typical older users. According to the investigation from the Psychology Institution of the Chinese Academy of Social Sciences, it reveals that currently we have about 91 % right-handers, 1 % left-handers, 2 % people who are mixed but used to the left hand and 6 % people who are mixed but used to the right hand. But in Europe and USA, the left-handers are relatively more than the right-handers and take a percentage of about 10 %. Thus, the objects for the human-computer experiment are mainly right-handers. Since the bodies of the aged are variously different, in order to make sure the measured results are true and precise to the greatest extent, the palm sizes for test are measured according to the hand dimensions defined by the national standard Human Dimensions of Chinese Adults to pick out the users with suitable hands. The final testing quantity is about 60 persons aged between 60 and 65, half females and half males.

## *3.1 The Operation Analysis of the Touch Screen Mobile Phone for the Old Users*

For touch screen mobile phones, there are generally 5 operation methods: operated by only the right hand, operated by only the left hand, held by the left hand and operated by the right, held by the right hand and operated by the left hand and operated by both hands. The test indicates that the operation methods described below are mostly used by the old people (Fig. 1).

As the picture shows: because of the changes on the sight and physical functions of the old people, the phones are mostly held the by both hands. This method is mainly used in a relatively quiet status just like sitting at home or standing. In this method, every fingers will be used and the operation will be much less physically

**Fig. 1** Held by the left hand and operated by the right

limited by the fingers and the mobile phone (such as the mobile phone size), which thereby creates a condition to realize the various design for the old people's gesture interactions. Currently, the touch screen mobile phones are mainly operated by a single finger and a few by multi-fingers.

### 3.2 The Analysis on the Distribution and Classification of the Old People's Hand Sizes

The tool used for measurement is electronic digital caliper. The research indicates that the fingers most frequently used in the operation process are the thumb, index finger, middle finger and ring finger, and the hand length and width also possibly have some effects on the users in holding the phone. Therefore, as requested by the measurement in vivo, with the reference of Handbook of Anthropometry, 6 indexes, including the length of the thumb, index finger, middle finger, ring finger and the length and width of the palm, were measured and recorded. When the measurement was being operated, the requirements for the measured person were (1) the finger was straight and measured vertically from the root cross lines to the end of the finger tip; (2) the palm was straight with 4 fingers together and measured vertically from the connecting line between the processus styloideus of radius and ulna to the root cross lines of the middle finger; (3) the palm was straight with 4 fingers together and the projection distances between the 2 sides of the radius and ulna was measured respectively at the horizontal levels of the second to the fifth metacarpus.

The measurement results were processed by the SPSS 19.0 software package. Table 2 shows the average values respectively for the measured females, males and all the measured specimens with respect to the length of the thumb, index finger, middle finger and ring finger and the length and width of palm.

For the K-M cluster analysis on the 6 indexes of the 30 measured female specimens, the hand sizes were divided into 3 types. Hereinto, 9 were defined as having small hands, 14 were defined as having middle-sized hands, and 7 were

**Table 2** The measured females, males, all samples of thumb length (mm), index finger length (mm), ring finger length (mm), palm length (mm) and palm width (mm) mean value

| Sample | Metrics | | | | | |
|---|---|---|---|---|---|---|
| | Thumb length | Index finger length | Middle finger length | Ring finger length | Palm length | Palm width |
| Females | 57.09 (3.51) | 66.96 (3.59) | 72.98 (4.04) | 67.86 (4.01) | 94.93 (4.04) | 73.3 (3.61) |
| Males | 62.05 (3.71) | 72.35 (4.24) | 79.01 (4.74) | 73.70 (4.52) | 104.91 (4.79) | 82.13 (4.23) |
| Population | 59.51 (4.37) | 69.59 (4.76) | 75.92 (5.33) | 70.71 (5.17) | 99.80 (6.67) | 77.66 (5.87) |

*Note* data in brackets is a standard deviation

defined as having large hands. For the K-M cluster analysis on the 6 indexes of the 30 measured male specimens, the hand sizes were divided into 3 types. Hereinto, 6 were defined as having small hands, 16 were defined as having middle-sized hands, and 8 were defined as having large hands. For the K-M cluster analysis on the 6 indexes of all the 60 measured specimens, the hand sizes were divided into 3 types. Hereinto, 24 were defined as having small hands, 19 were defined as having middle-sized hands, and 17 were defined as having large hands.

Table 2 shows the average values respectively for these 3 types of hands of the measured females, males and all the measured specimens with respect to the length of the thumb, index finger, middle finger and ring finger and the length and width of palm.

The variance analysis results indicate that these 3 types of hands of the measured females, males and whole specimens are all significantly different on these 6 indexes $P < 0.001$). Based on the above analysis, this experiment can be concluded to be:

(1) The hand dimensions of the measured females, males and whole specimens of the university students all conform with the normal distribution;
(2) Through cluster analysis, the hand dimensions of all the specimens can be classified into 3 types of large size, middle size and small size.

### 3.3 *The Measurement Statistics of the Sizes of the Touch Screen Mobile Phones for Old People and the Finger Quantity Contained by the Corresponding Size*

As people increasingly high demands on experience, led to the size of the touch—screen phones is constantly increasing. Gesture interaction and size of the touch—screen phones are inextricably linked. Touchscreen phone in the elderly

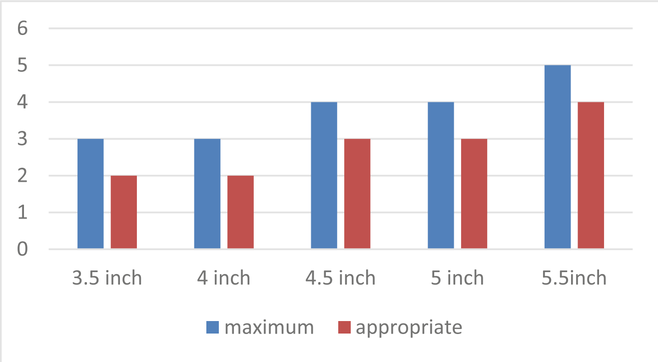



**Fig. 2** Phone size and finger capacity (h*orizontal coordinates* phone size and *vertical coordinates* finger capacity)

sign design time, you need to refer to the specific dimensions of the phone carefully to determine the sign of the corresponding task. For example, the same gesture for the task in 2.5 and 5.2 in. mobile phone, the zoom pictures of gesture interaction. As in 2.5 in. touch-screen phone has a size limit, it Cannot use two—finger pinch gestures to zoom the picture. According to the measurement of ergonomics, in 2.5-in. screen phones can accommodate a maximum of one finger, so the easiest way is to complete this task by clicking on the interaction between the gesture and control, or using double—click the picture to get the job done. However, in 5.2-in. mobile gestures for this task we will have more, such as using the gesture of Pinch with two finger. I selected a more typical size of the touch-screen phones on the market used to test the correlation dimension can accommodate the number of fingers. As shown in Fig. 2

The measurement statistics shows that, for the mobile phone of 3.5″–4″, it is most suitable and comfortable to contain 2 fingers and the maximum is 3 fingers. For the mobile phone of 4.5″–5.0″, it is most suitable and comfortable to contain 3 fingers and the maximum is 4 fingers. When the mobile phone is 5″ big, it is most suitable and comfortable to contain 4 fingers and the maximum is 5 fingers.

### *3.4 The Experimental Analysis of the Flexibility and Using Frequency of the Gesture Combination*

In the gesture designs, we have to find out the most flexible gesture combination in order to the usability of the gestures. This paper presents the flexibility and using frequency of the corresponding gestures for the old people by tests. The details are shown as below: this test is to measure the flexibility (the range of 0–100 points, more flexible and more points) and using frequency (the range of 0–100 points, more frequently used and more points) of each finger when the person is operating the mobile phone with 2 hands. The 5 fingers of the right hand is respectively marked by 1 (thumb), 2 (index finger), 3 (middle finger), 4 (ring finger) and 5 (little finger) which are short as 1, 2, 3, 4 and 5 in below measurement statistics (Figs. 3, 4, 5, 6, 7).

According to the above tests comparison, it shows single-finger operation is used more frequently than double-finger operation; the most flexible finger combinations are 12 (thumb and index figure) and 13 (thumb and middle finger) and they are more frequently used than other double-finger combination. For tri-finger combination, the most flexible combinations are 123, 134 and 234, and 123 combination

**Fig. 3** Flexibility of single finger


**Fig. 4** Common finger

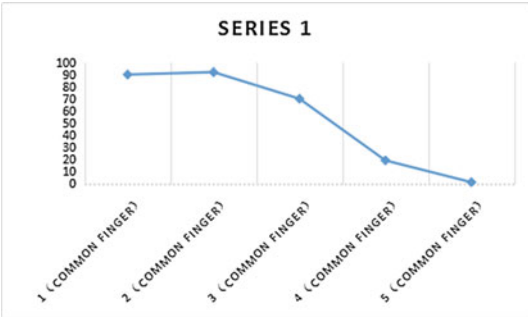
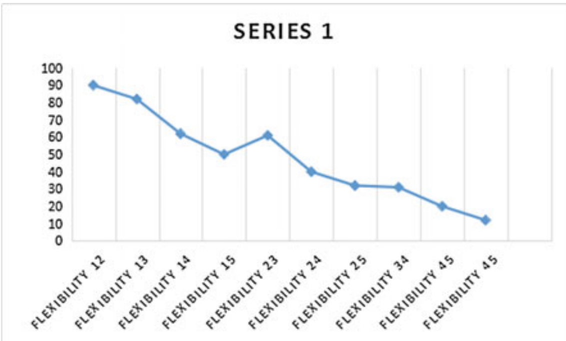



**Fig. 5** Flexibility of double finger combined



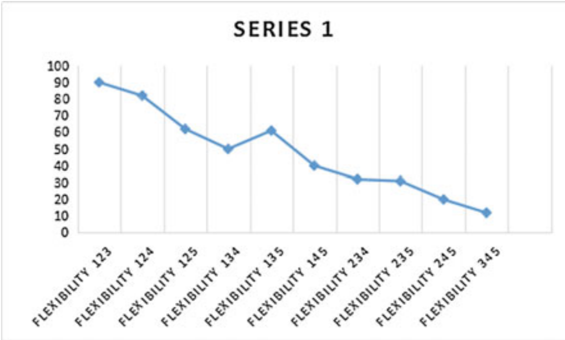



**Fig. 6** Flexibility of three finger combination

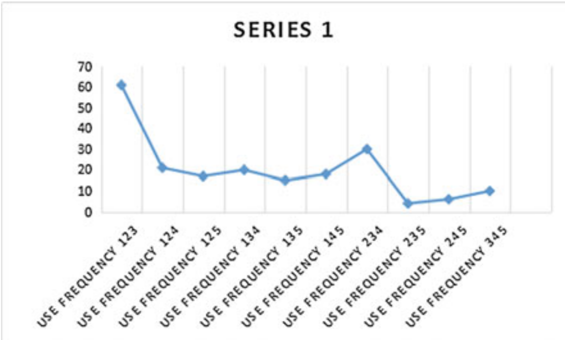



**Fig. 7** Operating frequency of three finger combination

is most frequently used. The operation with all the 5 fingers is most flexible, but this operation is used much less frequently because of the interface limitation of the touch screen mobile phones. Therefore, the flexibility and using frequency of both the single fingers and the combinations must be taken into account for the gesture designs. Generally, the selected gesture and combination should be comparatively advanced both in the flexibility and comfort level as well as the using frequency.

In conclusion, what must be firstly taken into account for the gesture designs of the touch screen mobile phones for the old people is the related human-computer engineering for the old people's fingers such as the operation methods of the touch screen mobile phones for the old people, the distribution and classification of the hand dimensions, the flexibility and using frequency of various gesture combinations and the experimental analysis research. Thus, the gesture designs can be more scientific and reasonable and consequently the gestures can be more easy and comfortable for the old people to use.

## 4 Conclusion and Expectation

At present, the utilization of the gesture-based interaction of the intelligent touch screen mobile phones by the aged is still at the start stage in China. We still have plenty of space for further development. By now, a number of the intelligent touch screen mobile phones for the old people have existed in Chinese market. But the related gesture interaction methods are variously different and lack of the intensive investigation and research on the aged. In addition, there are almost few old people speaking for themselves. As a result, the gesture interaction designs are less connected with the old people. Because the researches on the gesture interactions of the intelligent touch screen mobile phones are relatively less in China and it is quite hard to make investigation among the aged, the related researches get to be much more difficult. The effective information of the human-computer engineering of the gesture interactions of the intelligent touch screen mobile phones for the old people we got from this research and the corresponding design methods will play an important role in the gesture interaction designs of the intelligent touch screen mobile phones for the old people and other intelligent touch screen devices and also in the interaction research on the mobile phones for the old people.

This time we only make research on the human-computer engineering which is relatively more important for the gesture interaction designs for the intelligent touch screen mobile phones for the old people. We expect to fill in much more research contents, such as the research based on the cognition preference or emotion experiences of the aged, so that we can create a set of much more comprehensive gesture interaction designs for the intelligent touch screen mobile phones for the old people.

# The Study of Design of Senile Dementia Patients' Anti-lost Clothing Based upon Ergonomics

**Xiaoping Hu and Jiying Zhong**

**Abstract** Once diagnosed to have senile dementia elders tend to have incomplete cognitive ability and a weaken ability of everyday living. Many mental symptoms and behavioral disorder start to appear. In recent years, as the pace of life keeps on accelerating older people are left home solely or sent to the nursing home more commonly, the number of the missing sicken elders due the negligence of the caregivers has been increased. This has attracted some social media's attention. According to a five year research, 40 % of the elder with dementia in the community was reported missing and needed a third party to help them to get home. In Taiwan, about 71 % of elders with dementia had been lost while 60 % of the caregivers claimed that the patients they look after will go missing once in a while. Limited amount of research on this phenomenon has been conducted in mainland China except for a few about the mental disorder. According to the experts in the field more than 300,000 elders are missing every year. Bedsides more caring in daily life, various kinds of device are developed to prevent the safety loophole. Considering that different staged patients have distinctive manifestations, this research focuses on the nursing environment and the clothing requirement depending on the physical condition of the patient, to explore the potentiality and application of the engineering of ergonomics. As the technology incorporates with art more and more these days, it isn't merely just to cover and stay warm to wear cloth but also to be aesthetically successful. It is a trend to blend the ergonomic engineering with the clothing style.

**Keywords** Senile dementia patients · Anti-lost · Design · Communication technology

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# 1 Introduction

## 1.1 Purpose and Significance

This paper is to combine the human engineering and fashion design to apply in elder anti-lost clothing in order to explore the needs for the clothing based on the nursing environment and physical condition. Through the phased survey, via statistics and data, will find out the anti-lost clothing elements which be suitable for elders of different illness stage in order to reduce or even eliminate the phenomenon of elder lost, to ensure the health of elder's lives, and to reduce the occurrence of family tragedies.

Although I cannot afford to help the recovery of senile dementia patients. Therefore, under such a passive, it has important significance to improve the quality of life of the elderly in old and the social security by seeking a means of intelligent monitoring and master the patients' position.

## 1.2 Research Status

To embed the positioning electronic components into clothing, and through this way to have feedback information to remind, inform the caregivers of patient's location. At present, foreign research on smart wearing devices are typically focused on watch or wristband, sending out the location signal via Bluetooth to inform the caregivers. For longer distance, people can use an app on the phone to seek for help form people around. A more tradition way is to sew the personal information on patient's clothe in order for people around to see it and to be able to send them back home. I want to combine these two into one, that is, to embed a built-in informational device that can be seen virtually as well as send back the location signal to the caregivers.

# 2 Survey Results of Senile Dementia Patients' Actual Situation

## 2.1 Senile Dementia Patients' Characteristics Overview in Stages

Elderly people with the growth of the age, the shape changes significantly, such as waist and abdominal circumference increased but physical function and immunity decreased, basal physiological metabolism and body heat reduced. In addition to distinguish the various stages of patients' body characteristic, investigation content includes parents focus on fabrics, design aspects of classification, secondly considering the elements affect the stretching of the elder, so the placement of positioning components, and method of use requirements also should give full consideration to, and studies the application solutions.

As one of the three elements in design style, style is quite significant in designing clothes, especially in senile dementia patients' clothing design. Not only should we stick on the basic principle of design, but also must do the fundamental basis for the design of patients' body and its activities. Thus, in the style design, we must master the clothes' restricting factors for senile dementia patients' activities. At the same time, we should pay close attention to the functional requirements of the clothes in the market and the popular trend of product design, ensure it is attractive both on the function and design development.

Taking into account the different stages of the patient's daily condition is different, the questionnaire provides several different styles of clothing including shirt, vest, pullovers and jacket to summarize the caregivers' preferences. The results show that the vest and jacket popularity rages highest in the survey while the shirt selected proportion is almost zero, pullovers is under investigation for identity is much lower than the vest and jacket. As shown in Fig. 2, 55 % of respondents chose the vest, 24 % of respondents chose the jacket. In table one are the first staged patient who are relatively more active and younger. The second and third staged patient are weak and lie on bed. The suggestion from the caregivers are considerable since they are experienced (Fig. 1).

For the purpose that to serve all stage patients and suitable for all seasons, vest style is chosen to be the style for the research.

When comes to the selection of the fabric, it is first to think about the feasibility of bring it to production and whether it will help the function of its device. Also the fabric need to align with the style of the clothing. Elder's physical change is also taken into account. For example, during the winter time the cloth needs to be

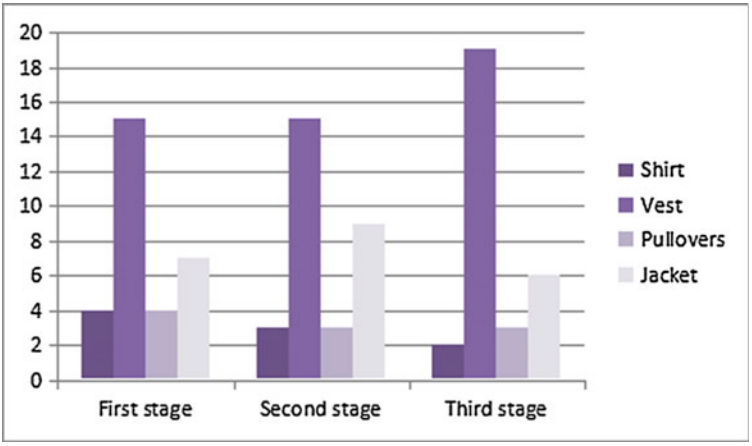


**Fig. 1** The choice of different staged patient's caregivers

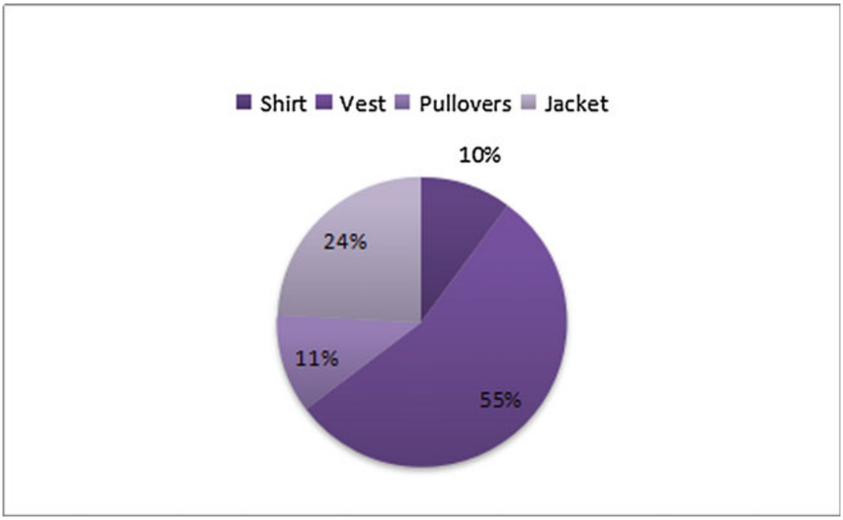


**Fig. 2** Percentage of various styles of clothing

protective enough to keep elders warm since their physical capacity is less than younger people. Also the cloth can't be too pressed to impeded elder's blood circulation. In the summer the cloth has to have air permeability and hygroscopicity, better to be light and thin and soft. Chemical fibers are bad because it can cause static electricity which are bad for skin under long term influence, can even cause senile pruritus eventually.

Therefore we concluded that, under the comprehensive consideration for children's delicate skin, and because they are sensitive to external stimulation, prone to infections and skin rash. And thus anti-lost clothes should choose elastic fabric; use its soft and wet absorption, air exchanging, natural cellulose and good warmth retention property. So while using the fabrics, we should give priority to the knitting fabric. Using a soft, elastic and unique knitting fabric with good characteristic wrinkle resistance and resilience. On the one hand, to dress in the process of technology application design, combine the positioning device integrated with the fabric performance; On the other hand, to ensure the rationality of fabrics and clothing garment structure during the design process.

## 2.2 *The Placement of Tracking Devices*

The location design of components is the key point in the whole design of the garment. On the one hand, analysis from the perspective of the visual appearance, due to the limit of the element size and the requirements of physical performance factors in the position of design, size should not be too prominent to avoid combining effects and clothing aesthetics; On the other hand, from the angle of safety comfort analysis, the elderly patients with dementia often lie in bed, due to the difference between properties of positioning component and textile fabrics is mainly manifested in the pliability, so in design of position, I will fully consider the performance of comfort and safety on clothing, in order to avoid placing on the joint activities of the human body. In view of this, according to the requirements of the overall design, I determine the several different positions, that is shoulder, protothorax, yoke, hem, the Medial suture, and investigate in the market, summarize their acceptance.

This investigation is also set to have three parts, the third staged nurse are experienced and know the habits and needs of the patient of dementia.

By the results of the survey analysis shows (as shown in Figs. 3 and 4), set the element in the protothorax and the medial suture are gain the more recognition. The degree of their preference is 50 and 24 %. From Fig. 3 shows that after the identity of shoulder position and yoke position is far lower than the protothorax and the medial suture position. The reason mainly lies in the position of the joint active point, that is, the shoulder end and the back shoulder blade. Under normal circumstances, the greater human joints force, resulting in the higher the frequency of the positioning element and the human skin friction, to bring inconvenience to children's activities and wearing uncomfortable. At the same time, due to the positioning element friction with the human body for a long time, the combination strength of the component and the fabric is reduced, and it's easy to cause the location of components defected from clothing, which will destructive use function. From the results of the survey analysis, the element in the position of hem of whole location design choice is small, it means that parents mainly taking into account the appearance of the clothing and the influence factor of human activities. Overall speaking, choosing the protothorax position to meet the requirements of safety and

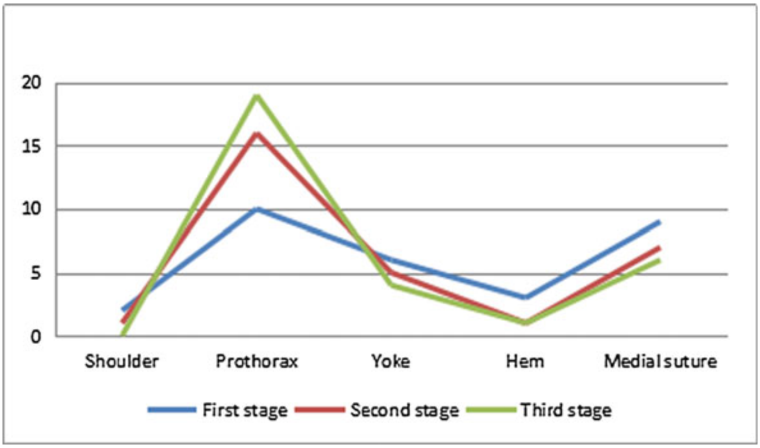


**Fig. 3** Comparison of caregivers' choice of placement of components

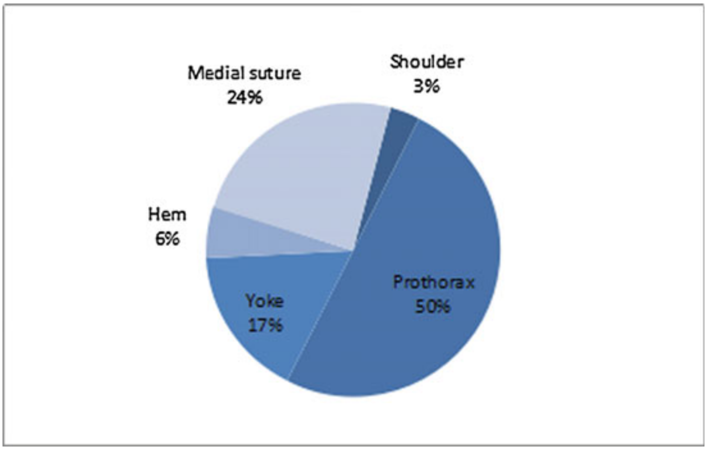


**Fig. 4** Total percentage of caregivers to component position

comfortable that taking into account the placement of components, but also the elderly to facilitate the display of information.

# 3 Component Condition Analysis of Embedded Elements

## *3.1 Division of Patients' Activity Area*

Patient's area of activity are divided into safe zone, active zone and separation zone. Safe zone is the area that are detectable by the caregivers and where elders have companions. The activity zone is where elder move within a fenced district and they can move alone. The separation area is anywhere outside the activity area. The positioning component embedded to the clothing can tell us the position of the patient through the anti-lost network. It will trigger the alarm when a patient is about to enter the separation zone, actively prevent the missing of the patients.

## *3.2 Classification of Communication Technology*

Bluetooth is a wireless technology for short distance wireless communication, which can exchange wireless information between a number of devices including a mobile phone, a PDA, a wireless headset, a notebook computer, and a related peripheral device. In addition to this, Bluetooth adopts distributed network architecture and fast frequency hopping and short packet technology, which supports point-to-point and point to multipoint communication.

Wireless Fidelity is a short-range wireless transmission technology, able to support Radio signal for Internet access in the hundreds of feet.

Infrared transmission is a kind of point to point transmission mode, which is suitable for low cost, cross platform, point to point high-speed data connection, especially the embedded system.

ZigBee is an emerging wireless network technology, with low power consumption, low data rate, low cost, high reliability characteristics of short distance, has the function of geographic location. Thus can be timely access to the location of the target node to realize the dynamic monitoring of moving targets.

## 3.3 Types and Differences of Communication Technology

In terms of the communications technology, research has been underway to classify and sort out several widely employed technology for tracking. According to its principle, I will analyze its pros and cons features in the respects of security, interference, involving distance range, relevant methodology and cost as well as the feasibility of embedment into clothing. While considering the problem of the clothing washing, equipment maintenance, and the condition of being fully enclosed or semi-enclosed, we will compare relevant data to select from these types of communications and electronic equipment applicable to each of the three stages of patients (Table 1).

**Table 1** Comparison of the performance of Bluetooth, Wireless Fidelity, Infrared and ZigBee

| Category/condition | Bluetooth | Wireless fidelity | Infrared | ZigBee |
|---|---|---|---|---|
| Transmission speed | 1.1–2.1 Mb/s (even higher) | Can reach 54 Mbps | 4 Mbps | 10–250 kb/s |
| Transmission distance | Generally within 10 m | Range of hundreds of feet | Communication distance is short | Transmission distance of 10–75 m, after the expansion of up to a few hundred meters, or even thousands of meters |
| Standby time | Several weeks | Hours | Longer than others | In a low power standby mode, two section no. 5 battery can support 1 node for 6–24 months or even longer. |
| Security | Can encrypt | Exist security risks | It has strong security | Provides a three level security model |

Bluetooth technology advantage: In the 2.4 GHz band which is an industry, technology, medical radio band without application license. Bluetooth technology has a wide range of applications, low power consumption, small size and low cost chip solutions that can be applied to very small devices.

Wireless Fidelity's outstanding advantages to be as follows: First, based on the Bluetooth technology of radio coverage is very small radius of about only about 50 ft, while the Wireless Fidelity coverage radius of up to 300 ft or so. Second, although its data security performance is worse than Bluetooth and transmission quality also needs to be improved, but it's really speedy for data transfers.

The main purpose of Infrared communication technology is to replace the cables connecting the wireless data transmission. Its interface can save the cost of download or other information exchanges; Due to the need to transfer information docking, it has strong security. Relatively, its communication distance is short and in the process of communication can not be moved. Moreover it will be interrupted in case of obstacles.

The advantages of ZigBee could be summarized as: By greatly simplified protocol (less than 1/10 of the Bluetooth), the demand for communication controller can be reduced. ZigBee work in the low rate with 250 kbps (2.4 GHz), 40 kbps (915 MHz) and 20 kbps (868 MHz) of raw data throughput, to meet the demand of low speed data transmission applications. ZigBee has a faster response speed. Only need 15 ms, it can be transferred from sleep to the working state, similarly, Just 30 ms, the node connection can enter the network. It can be argued that the above features are beneficial to further save the electricity.

ZigBee and Bluetooth are both used in the 2.4 GHz band, which relatively has weak ability to through the wall. The difference is that ZigBee uses DSSS spread spectrum, while Bluetooth using FHSS spread spectrum. It depends on product positioning in the market to use DSSS or FHSS, because they can solve the transmission capacity and characteristics of the wireless local area network, which including the anti-interference ability, using distance range, broad frequency the size of the small and transmit data. DSSS technology suitable for fixed environment or application of higher transmission quality requirements, therefore, wireless plant, wireless hospital, online communities, mostly using DSSS wireless technology products. While FHSS is mostly used in fast moving endpoint, such as mobile phone, the wireless transmission technology of using FHSS spread-spectrum technology.

## 4 Conclusion

Since to master and realize intelligent technology has a time limited, and my interdisciplinary knowledge structure system is not complete, especially the subject of positioning technology is not comprehensive, resulting in many problems and deficiencies in the research. Mainly embodied in the subject of the relevant professional knowledge structure, and the undetailed test, it is necessary to further improve and perfect the analysis. But I hope that through the investigation of caregivers and senile dementia patients' needs, as well as the communication technology of the data collection and comparison, we can find a suitable way for children to anti lost. Also hope that I can do my own part of the strength to combine the clothing design and human engineering to solve the social problem of senile dementia patients lost.

# Evaluating Interfaces and User's Profiles

**Lucila Mercado Colin and Alejandro Rodea Chavez**

**Abstract** To show the relevance of the process of User Centered Design, particularly the stages of inquiring and evaluation when involving real user is crucial to thoroughly approach them. It is important to establish consistency of interface design complexity accordingly to the user's experience, to properly drive the design process by defining the level of development of a project. Design Process could be defined as a set of successive steps that aim at finding a solution to interface design. A set of qualitative and quantitative data could be gathered when approaching to Users taking them into account as a systemic element, which in integration with the other subsystem elements (Object, environment and Activity) allows arising information to be identified, collected and with it, feed backing the design process.

**Keywords** User's characterization · Ergonomics systemic approach · Design process

## 1 Introduction

The design process "generally emphasizes the importance of generating a solution concept at an early stage of the process, thus reflecting the nature of design thinking aimed at problem solution. This initial solution conjecture is then subjected to an analysis, evaluation, refinement and development. Sometimes of course, the analysis and evaluation stages show fundamental flaws in the initial guess, and therefore it has to be abandoned, generating a new design concept and starting the cycle again (Cross 1)". "Well defined problems have a clear goal, wright answers and rules or

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well-known procedures that should gather an answer. The characteristics of not well defined (or wicked problem) could be the following" [1].

In the field of applied ergonomics to Interface Design (which considers people, activities, mediating objects of these activities and the use environment) it is been an increasing interest to integrate the users during the development process of those interfaces; the named User Centered Design (UCD) approach considers diverse kind of evaluations, which allows to observe the level of development reached out in an specific design process.

Three techniques that help define user profiles are considered: designing user profile, scenarios and use and design requirements (Fig. 1).

In order to improve the inquiry stage of the design process through that approach, it is been resorted to using diverse techniques that provide qualitative and quantitative data, necessary to include the social, emotional and cognitive user's characteristics during the development of the interface design (Table 1).

Those inquiring and evaluating stages are tightly linked, because specifications corresponding to the inquiring stage, done during problematisation, are the ones that must be evaluated and assessed across the design process.

For instance, during the inquiry stage and after analysis of the information the following aspects are determined: the necessity or problem to solve, the objectives persecuted, the system's limits, the attentional focus must be set, the design restrictions must be stipulated and precise evaluation criteria are established for the final solution. Moreover, the design applied assessment is a process that allows to identify the level of development of a project with respect to the established objectives, because through the application of several tools, useful data are obtained that allow the formulation of judgments for decision making, that will provide feedback to the design team to continue to refine the process and outcome of the design project.

At the inquiring stage is crucial to firstly address the question "what will solve the problem" (problematize) and secondly, is mandatory to explain how to do it (conceptualize); thirdly, to present solutions (models) during development stage, and finally, to assess the characteristics of each possible solution in the evaluate stage.

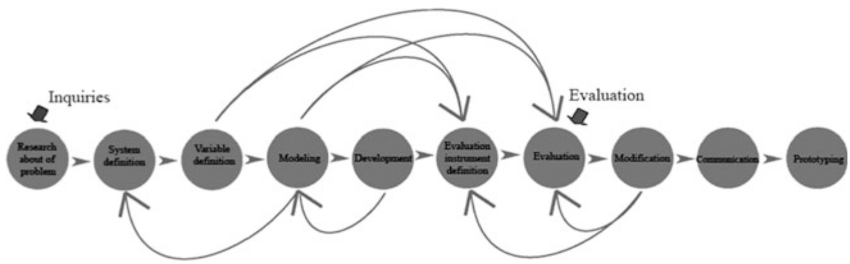


**Fig. 1** User centered design process (UCDP) model from ergonomics perspective

**Table 1** Main stages of the UCDP model

| Stage | Action |
|---|---|
| Inquiring | It provides starting information about the problem to solve, useful in defining what aspects will be considered at the project |
| Definition of the system | In which is needed to establish a context of use, who the users are, what is the activity developed by the users, which objects do mediate such activity, features of the environment of use that may impact positively or negatively in the task, in other words, definition of the system narrows the system boundaries |
| Definition of variables | It means to be aware of which aspects we want to control or to observe during the design process |
| Definition of instruments | There are selected the correct type of appropriate instruments to obtain the required information. It refers to the media that allows obtaining qualitative or quantitative e information relating to any (cognitive, physical, emotional or social) human dimension |
| Evaluation | At this stage, there are used different instruments to measure or to observe the interaction of the system's elements, in order to determine if there are found problems in both, the design process and the resulting design proposal obtained |
| Modeling | This stage is carried out considering the information gained from the feedback process promoted by the assessment stage so, it is based on real users profile and not only on a hypothetical one |
| Communication | This is the stage where are already known the technical, formal and of use qualities of the product, and are about to be communicated to who will carry out the process of completing the prototype |
| Prototyping | It gives a detailed caption of the specific product qualities for doing or manufacturing it |

Adapted from Mercado and Rodea [2]

The assessment is a process of obtaining information and using it through the application of methods and techniques that allow identifying the level of development of a project with respect to the objectives previously specified. The main goal of assessment stage is making useful judgments for decisions making, i.e. allows feed backing design team during the design process.

At this point is useful to clarify when referring to evaluations in UCD processes, that are classified according to their purpose (diagnosis, formative or summative); the moment of its application in the Design process (early or late); those are also segmented accordingly on the type of participants in the test (beginners, advanced or experts users); or depending on the kind of the observed data (qualitative or quantitative); evaluations are even segmented by the User's dimensions to be assessed (physical, cognitive social or affective).

Generally, when each project design is developed, it should be determined all useful aspects that would feed the design process. The growing concern of designing products that meet the needs of users from their perspective—and not designer's—has revealed the advantages of applying the UCDP. These processes are characterized among others by:

- Integration of end-users in the stages of investigation and evaluation.
- There is an appropriate distribution of the cognitive demands of objects with Users.
- Iterative design solutions allow feedback the whole process.
- Approaching to problem has a systemic vision.
- Capabilities and limitations of users in their physical, cognitive, emotional, and social dimensions are clearly identified.
- The products of design process (resulting designs) are evaluated at some point validating it.

By emphasizing the inclusion of end-user in the interfaces for interactive systems designing process, accentuates at this process Users are considered in a systemic context. This means that the user's characteristics, as well as the objects which mediate its activities at specific use environments when interaction is to be carried out.

Design processes focused on people consider—as a fundamental part of its focus—the possibility to identify, to capture and to evaluate the results of these processes in function of user goals, and the objectives of the project meaning, it is not only important the process but the result.

Since the 80s of last century, Design has been enriched by a number of approaches that promote product development teams to approach people who should use these products. This phenomenon has been considered in different ways. From one that rises only an approach for getting general characteristics related to desires, behavioral, aspirational or motivational of users, to another which integrates Users in the development groups, and even reaching out a processes of co-creation. Such approach has led to gain a better understanding of Users as of their motivations and needs, positively impacting the search for efficient processes to get effective and more satisfying products, easy to use for different types of users.

In any case, it is important to consider in a way, part of the success development of the design process rely on the accuracy with designers get know Users, as well as on the designer's skills to convert the contextual information—including individual characteristics—in design features which optimally respond to User's needs.

## 2 Speaking of Users

To speak about User in terms of design should mean we know the identity of the people for whom a design is directed. However, quite often User is mentioned as a formless, aimless subject, without differentiated skills, without previous experience that could aid guiding designers—to designate—how the way interaction with design products should be.

Nevertheless, during the lapse of interaction with products Users expresses their selves, leading and reflect their experiences, their skills and knowledge in various ways, and is for this reason and aiming to get closer to the observation of users and their differences, here are stated some aspects that are intended to help identify aspects of the design process that would allow defining the User's characteristics: the User profile.

The User Centered Design is a tool that focuses on the design process to encourage development teams has a realistic approach to Users, with the aim of knowing and designing for real people who have needs, constraints, opportunities and expectations.

### *2.1 The Systemic Perspective and Its Relationship to the Requirements*

To ensure the phases and the result of the User Centered Design Process applied to the development of interfaces is being satisfactory and efficient, it is necessary to observe the interaction of the system (uoae system: user-object-activity-environment) running simultaneously, and observe emerging information from such interaction, meaning those features which arise from the interaction of specific variables considered in that system; to observe how the variables in uoae system are related, how does impact each other to define the technological and of usage characteristics, and of interface design in an interactive system.

- In systems variables have a common goal.
- All variables are impacting each other (interdependent).
- All variables are interrelated.
- Emerging characteristics of the system are observable and in these:
  - "A User is involved.
  - That User is doing something.
  - That User is doing something with a product, system, or other things" [3]
  - That User is doing something with a product in a specific use of context.
  - The capabilities and limitations of Users in their physical, cognitive, emotional and social dimensions are considered, related those with the User activities with the product, and having a perspective in which the observation of information allows be both, qualitative and quantitative.

Through the uoae analysis system is feasible to identify how will relations of binomial variables would be, user-environment, environment-activity, activity-object, object-user; the interrelation of these variables will identify the conditions, resources, knowledge and skills require by User to interact with the system; This helps to define the limits and scope of the system, which promotes knowledge of the context in which target Users will be involved.

During the inquiring stage is necessary to address the information what will solve the problem (problematize); This involves knowing who, what, when, where and how the system and its interaction variables works, taking into account user-object-activity-environment variables, which obviously consist of raw material for the definition of the system development.

An evaluation of interface design should observe all aspects that impact on the User interaction—with the interface and the environment of use—, i.e. systemic approach must aid responding to the questions: Why to evaluate?, What to evaluate?, Where to assess?, When to evaluate?; all questions are associated with the objective of design aim of evaluating the complexity of interfaces related to the User experience (which involves affective, cognitive, physical and social aspects) so that the methods, techniques and tools for inquiry or evaluate must be properly selected and applied during the interfaces design process.

Evaluation of the interface is useful for feed backing during the design process. Such evaluation requires considering consistency between interface complexity and experiences of users, and because that it is important to define a typology of the user, centered in the relation of user-object-activity.

This implies that it is necessary to determine the objectives that meet the designed object in that the objective is related to the characteristics to be evaluated, if there are not an objective, evaluations should not be useful to feed backing processes, neither can be set the level of development reached a project when complete.

## 2.2 The Tools

In the User Centered Design processes there are two stages that are particularly sensitive due to involve Users: The inquiring (stage where problematisation is done, leading to a definition) and the assessment of the solutions obtained or evaluation. Both are of paramount importance in the UCDP cause it is in these, where materializes the possibility of integrating Users at various levels, given that at the inquiry process is required approaching to Users in order to obtain useful information for problematisation, and at the evaluation stage is feasible to compare the level of development achieved in the solutions to the problem.

During problematisation arises the need to implement tools to help determining which variables are interrelated. This is a particularly sensitive stage to define the User's characteristics.

The stages of inquiry and evaluation are necessary in order to use a technique of investigation. The research technique is a step, a tool for both qualitative and quantitative information. There are various User Centered Design appraisal strategies which provide—both objective and subjective data—useful to measure results of a design process, as well as provide an approach to the development of a design process itself, with tools that allow early or overall assessment of each design process stage.

To make an assessment (and identify systemic relationships established between the variables of the design process of interactive systems interfaces) it is needed to considerer the application of methods and tools that would incorporate human factors considerations into the process of designing and evaluating human-computer interfaces which would:

- Be usable also by non-human factors specialists (e.g., interface designers) for whom direct availability of human factors results is important.
- Be explicit so as to permit measurements and sufficiently standardized to be replicated [4].
- Consider the goals, desires, knowledge and skills in design.
- Determine the demands that will have the object to the user (cognitive, physical and emotional) and demands User should have over the object (response times, performance and capacity).

### 2.3 Person-Scenario-Requirements

The analysis of the characteristics possessed by people (previous experiences, attitudes, knowledge, technical skills, etc.) is required to determine the characteristics of the interface, in terms of their level of complexity, cognitive or physical demands that does the object to the User, to interact in a satisfactory and efficient manner and demands that the user makes the object considering its technical and operational characteristics.

To define the user's typology, it is necessary to recognize the mental model expert, advanced and novice users have. Accordingly with Romero (in Knapp) [5], some aspects of the mental models evolution phases are as follow (Table 2).

The way users solve problems, is based on the type of experience that has been exposed and the goals he or she have to use that object.

Some of the important aspects to define user's profiles (not necessarily a unique profile expertise level) should consider the patterns of group behavior and the differences that distinguish different groups within a population.

Another aspect to be considered is the User's goals are related to the reason which he or she uses an object. For this reason it is vital throughout the design

**Table 2** Aspects of the mental model evolution phases

| Stage | Characteristics of expertise |
|---|---|
| 1st stage. The novices | Dominance of perceptual aspects<br>Knowledge transference from previous environments |
| 2nd stage. The concrete expert (advanced) | Interpretation according to an entrenched but inaccurate mental model<br>Disorientation in the face of novel and scarce flexibility.<br>Conservative style of navigation<br>Quick decision making but frequent errors |
| 3rd stage. The expert | Capacity of transferring knowledge into new situations<br>Rapidity and precision in execution |

Adapted from Romero in Knapp [5]

process to define a lens with a systemic vision, i.e.: Who used the object or system? (User), what need requires solving? (Activity) What object solves this need? (Object) Where the object does is used? (Environment), allowing saying that a systemic process considers the user, carrying out development activities mediated by objects in a specific application environment. The filters that allow contextualizing goals among others are: the desires, needs, motivations, habits, attitudes and context of the user.

User profiles are connected to the scenarios putting in context the characteristics of users and their responses (actions) during interaction with system.

The scenarios allow understanding people, the difficulties faced during the processes of interaction, how they solve problems that are presented and decisions that are active in the process.

To meet the people it is needed to apply a set of techniques that allow the observation of information which would be valued in the context of user goals and design objectives.

Scenario planning (narratives) is useful for describing how the scenario can aid defining the requirements for interface design by focusing on the action of the user with the system. Requirements should establish the specific characteristics of use, performance and technological aspects, meaning how the system is, what it does and how it does it.

The scenarios describe how tasks are performed with the system, these can include other actors. The scenarios are linked to the processes of inquiry and evaluation to jeopardize the relationship of the various users with the features of the interface. It is possible to construct two scenarios, applicable at different times of the design process (inquiry and evaluation); it is also feasible to modify their level of complexity. The first type of scenario is linked to the inquiry and permits to describe perceptions, desires, motivations and interests of users, while the second relates to the evaluation process, both early and global assessments; the early ones to give feedback to the process and the global evaluation to determine the level of development that the process got.

It is important to delve into the techniques that help the designer to define and test user profiles, as well as to identify the nodes on which it is productive, given the level of feedback into the design process, that generates the insertion of users scenarios, development of strategies and techniques to define accurately which nodes would better allow test development conditions of the development process.

Mediated by observing scenarios it can be set attributes to determine the technical characteristics, usage, and performance. This part of the observation of the characteristics of the design process, the inclusion of users in such process, the steps in which the designer has the ability to approach to Users in order to determine their characteristics and therefore, the object features that meet the User's needs.

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# Analysis of Glasses Wearing Comfortability Based on 3D Head Shape Features

**Zhelin Li, Xiaomin Zhang, Jiaxin Zhang, Lijun Jiang and Guangzheng Yu**

**Abstract** It is hard to find comfortable glasses for young people in China, due to the facts that Chinese glasses deign industry lacks the 3D head shape data of youngsters, and the glasses are of monosize and designed following the Europe and America styles. Considering this situation, this paper analyzes the 3D head shape based on glasses wearing comfortability (GWC). Through comparing the 3D head shape of young Cantonese in China with the worldwide average people KEMAR, it is shown that the GWC can be improved by considering some head shape features when designing glasses. Firstly, some effect factors of WC are proposed by interviewing 136 youths who have worn glasses for a long time. Then, the head areas which interact with glasses are found by analyzing glasses construction parameters. Finally, by comparing head shape features of 62 Cantonese and KEMAR, it shows that a big difference exists in the temples contour. Therefore, it is concluded that the GWC can be improved with consideration of the bend point long, the external angle and the profile shape of glasses temples based on the dimensions of the wearers.

**Keywords** Glasses design · 3D head · Comfortability · Temples contour

## 1 Introduction

It is pointed out by the 'Report of Chinese Students' Physique in 2010', which is led by Chinese students physical health research group, that the shortsighted rated Chinese teenagers is at the second place and the total number already reaches 400

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million [1]. Now, China has become the No. 1 country of producing and consuming glasses. However, it is not easy to get a pair of comfortable glasses for Chinese consumers since the existing methods of designing glasses in China are adopted from the methods of Europe and America, which are only based on head features of western people [2, 3].

In papers [4, 5] Tang et al. measure two dimensional face data of 500 adults and propose a method to measure 2D facial data when designing glasses. But this method has its drawbacks since human face is of three dimensions. MAKIKO KOUCHI points out that high GWC can only be acquired by appropriately adjust glasses frame dimension to facial morphology [6]. This conclusion is proved to be valuable through analyzing 3D face characteristics of 56 Japanese males. Ball et al. collects data of head features of 2000 people from 6 different areas in China and analyzes the significant differences of head features between Chinese and westerners. However, the GWC is not taken into account [7]. Mashima et al. study the relation between the clamping force of glasses frame and ear pain. By measuring the head data and then adjusting glasses frames to reduce the clamping force the comfortability is improved [8]. But the parameters of glasses frame and head are related to the comfortability are not pointed out.

By measuring the weight and its nose holder areas of 155 pairs of English glasses, Walsh finds that only 5.8 % of glasses have the nose holder area of 200 $mm^2$ and few glasses can meet the requirement of BS EN ISO 12870: 2004 (BSI, 2004) [9]. Chiu suggests that the comfortability depends on the balance and stability between glasses and nose and ear [10]. Griffin and Yang design a new type of glasses without arms. However, their innovation focuses mainly on mechanical design, while GWC is not concerned [11].

This paper aims to improve GWC based on analysis of the three dimensional head shape features and discussion of the effect factors of GWC. First, through analyzing structure parameters of glasses related to GWC, the areas of head interacted with glasses as well as head parameters with correlation to WC are found. Then, by comparing the head features of 62 Cantonese and western standard head shape, the differences of the head areas interacted with glasses of them are drawn. Finally, the glasses parameters affecting the head areas, with which glasses interacted, are proposed and some suggestion of designing glasses are given.

## 2 Paper Preparation

In order to study the relation between the structure of glasses and GWC, 3D head data of KEMAR model and lively human are collected by high-precision scan device. After that, unified coordinate is built and data processing such as rectification is done to make comparative analysis of head contour with association with the legs of glasses.

## 2.1 Structure Parameters of Glasses Arms

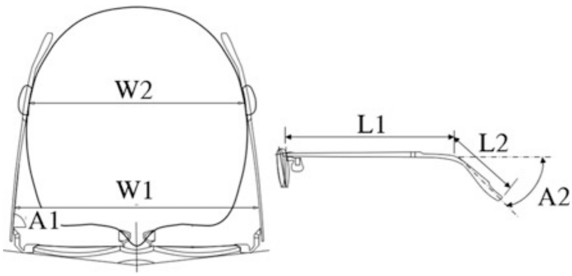
A pair of glasses consists of arms, frame, nose pads, glass, and ext. In this paper, only GWC with consideration of glasses arms is discussed. The structure parameters of arms includes L1 (Length from hinge to point of bend), L2 (Length of bend), W1 (Width of arms), W2 (Width of frame), A1 (External angle between arm and frame), A2 (Angle between bend and arm body), as can be seen in Fig. 1.

## 2.2 Survey of GWC

In order to find the factors of GWC, 136 Cantonese who have worn glasses for a long time are interviewed and 132 pieces of effective interviews are acquired. The result shows that 81.7 % of the 132 participants complain their glasses arms are not fit them, which dramatically reduces their positive feelings about GWC. The unsatisfied problems existing in glasses arms are given below:

A. *Length from hinge to point of bend* (*L1*)
   (1) 26.4 % of these interviewees say L1 is shorter than what they want, which causes the weight of the glasses is concentrated on their ears resulting in their ears swelling and pain. (2) The left (73.6 %), in contrast, say L1 is longer for them, which will even affect their eyesight if they wear such kind of glasses. This is because the weight of glasses is shifted from ears to the nose pads when L1 is longer for wearers, which causes nose pads sag and then makes the glasses optical center not aligned with the pupil.
B. *External angle between arm and frame* (*A1*)
   91.4 % of the effective participants give a response of too less A. These symptoms are concluded as follows. (1) The head areas contacted with the glasses arms are sagged. (2) The temples oppressed by the glasses arms make them dizzy. (3) Long term relative heavy pressure on the ears causes headache.
C. *Angle between bend and arm body* (*A2*)
   41.7 % among them enlarge A2 by themselves to increase the degree of coincidence in order to decrease the excessive weight force endured by noses and shift part of it to the ears.

**Fig. 1** Structure of glasses arms



### 2.3 3D Head Shape Data Collection

The device of 3D data collection is HandyScan produced by Creaform Company with a scanning resolution of 0.5 mm which meets the standard of ISO 15535-2007 [12]. In this paper two kinds of data are used. One is from the physical model of KEMAR based on the average of European head shape data [13]. The other is from the 123 teenagers in Canton, China, where the good data from the 62 males among them for subsequent analysis (Fig. 2).

### 2.4 Coordinate Registration

Due to the collected data get from device of HandyScan are based on the effective data scanned for the first time which as the origin of the coordinates, there is no any comparability among them. To make the data in a unified coordinate, Frankfurt plane is used as the reference plane. The plan can pass the left (right) outside the eye point, left tragus point and right tragus point. Specific procedures are given below, which are shown in Fig. 3.

(1) Select the midpoint between left tragus point and right tragus point as the new coordinate origin and then translate the old origin coincided with the new one.
(2) Rotate the coordinate regarding the Z-axis and Y-axis as rotation axes respectively to make line between left and right tragus point overlapped with X-axis.
(3) Rotate the coordinate around X-axis so that left orbital point is on X0Y plane.

Since the number of the collected data is up to 1.3 million, comparative analysis of head shape data from KEMAR model and the 62 lively human beings is a useful method. This paper analyzes glasses registration by establishing a reference plane in 3D coordinate system like the way used in papers [15]. Assuming the glasses arms

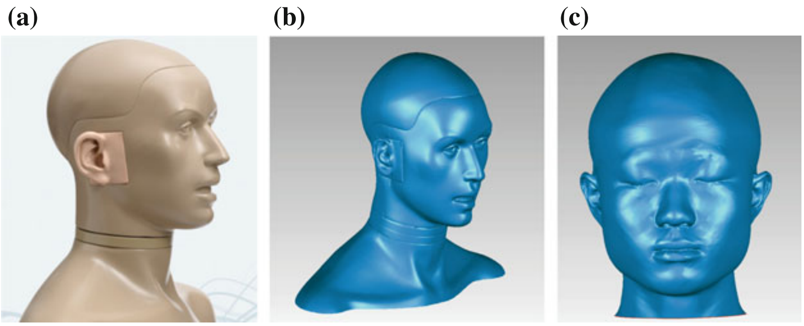



**Fig. 2** 3D digital model based on a 3D scanned device **a** KEMAR physical model [14] **b** KEMAR digital model **c** lively human scanned model

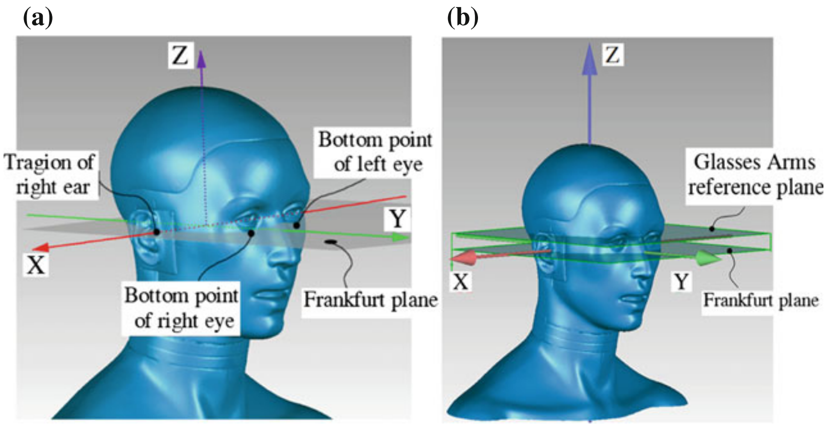



**Fig. 3** Coordinate registration of head shape data. **a** Create frankfurt plane **b** create glasses arms reference plane

as a plane curve, the reference plane of the glasses arms will be formed by the bending points and hinge center of the two glasses arms. This plane should be parallel with the Frankfurt plane. By mapping glasses features to human heads ones the reference plane is just the plane which passes through the upper ear root and at the same time parallels the Frankfurt plane, as can be seen in Fig. 3. To compare contour of each glasses arms based on different head shape afterwards, these contours should be in the same plane, so X0Y plane is moved to the reference plane.

# 3 Analysis and Discussion

In this paper, KEMAR model is set to the reference model and the 3D head shape models of teenagers in Canton, China, as the test models. After aligning the ori-gins and 3D coordinate systems of the two models, the differences of the 3D head shapes can be shown clearly. Then by using X0Y plane slicing 3D head shape, the head contours in the reference planes of reference model and the test models can be obtained.

## *3.1 Case Analysis*

With the registration of the 140405003th volunteer and KEMAR 3D head shape (shown in Fig. 4a) and then slicing and getting the contour data on the reference plane, differences are clearly shown in Fig. 4b.

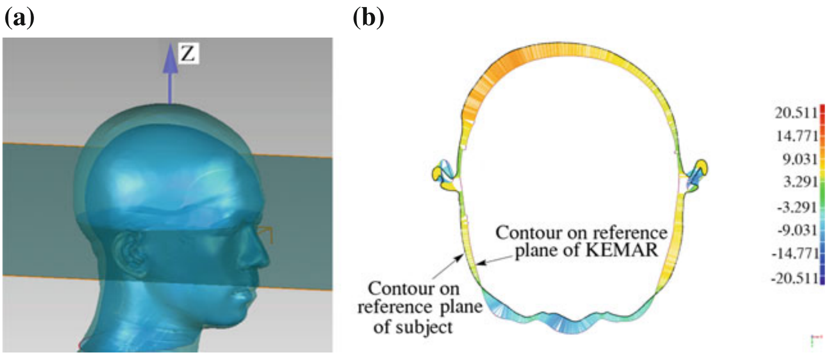



**Fig. 4** Head contours of KEMAR model and the 140405003th volunteer **a** 3D head shapes superposition **b** head contours comparison

In Fig. 4b there is big difference of head contour between the 140405003th volunteer and KEMAR model. The 140405003th volunteer has shorter forehead, smaller inclined degree of the plane from his ear to his forehead, and has a bulge contour on the temples. However, based on westerner head features, the consideration of curvature from trailer coupling to the ear is overlooked. The 140405003th interviewee says that there is a dent on his temples due to the bulge is pressed by the glasses arms. Moreover, because of his allergies to mental he can only choose plastic arms. Table 1. shows the analysis results of deviation distribution after comparing the 2238 samples of the contours of the two models.

In Table 1 it shows that the maximum positive deviation of them is 11.389 mm, the maximum negative deviation is −16.841 mm, and the average is 6.167 mm. There are 1092 points with deviation between −3.291 mm and 6.161 mm, accounting for 48.793 %, while there are 573 points whose deviation is between 3.291 mm and 6.161 mm, taking up 25.603 % of the total numbers. Moreover, the head contour area of KEMAR is smaller than that of the volunteer.

**Table 1** Deviation distribution of head contour of the 140405003th volunteer and KEMAR

| >= Min (mm) | <Max (mm) | Number of data | Percentage (%) |
|---|---|---|---|
| −20.511 | −17.641 | 0 | 0.000 |
| −17.641 | −14.771 | 3 | 0.134 |
| −14.771 | −11.901 | 19 | 0.849 |
| −11.901 | −9.031 | 116 | 5.183 |
| −9.031 | −6.161 | 159 | 7.105 |
| −6.161 | −3.291 | 284 | 12.690 |
| −3.291 | 3.291 | 519 | 23.190 |
| 3.291 | 6.161 | 573 | 25.603 |
| 6.161 | 9.031 | 279 | 12.466 |
| 9.031 | 11.901 | 286 | 12.779 |
| 11.901 | 14.771 | 0 | 0.000 |

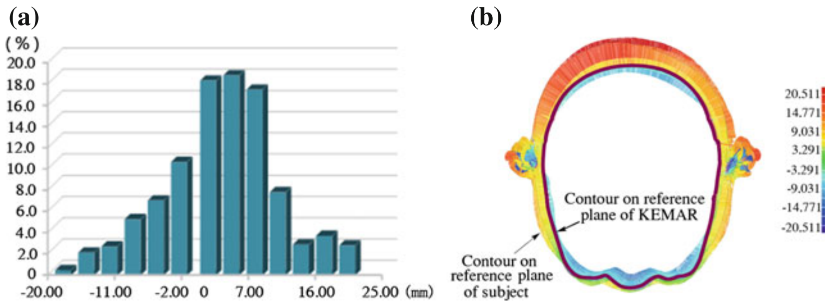



**Fig. 5** Head shape comparasion of KEMAR model and 62 teenageers of Canton, China **a** percentage deviation distribution **b** contour comparasion on the reference of glasses arms

### *3.2 Samples Comparison*

By superimposing the head contour of the 62 volunteer and KEMAR on the reference plane of glasses arms, a comparative analysis conclusion can be drawn, which is shown in Fig. 5.

Figure 5 presents that the deviation is a normal distribution and is mainly located in three positive intervals. In Fig. 5b it can be known that the both sides of westerner head are smoothing slopes so that only the length of the bending part and external curve degree of glasses arms should be emphasized. However, the temples of the teenagers are bulged out observably while ear roots opposite to temples are sagged. Therefore, it is inconsiderate only considering the external curve degree. This is because if the degree is too small glasses arms will oppress temples while if it is too big, it will increase the width of the ear root and make the weight of the glasses shifted from the ear root to the nose pad. In the other hand, a proper curvature is a necessary consideration to make an enough gap between the head and the temples.

## 4 Conclusion

This paper compares the three dimensional head shape features of Chinese teenagers and KEMAR. It is shown that there exist big differences of head contour that glasses interacting with, and the GWC can be highly improved based on the following two considerations: (1) make these differences as important basis when designing the bend point long, the external angle and the profile shape of glasses arms. (2) The aforementioned three aspects of glasses arms can be adjusted freely within a limited range based on specific head shape of each Cantonese, considering individual differences.

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# Developing of a System for Measuring and Evaluating the Hand Stress in Relation to the Strain Index

**Peter Gust, Aydin Ünlü and Max Hoppe**

**Abstract** To assessment the hand stress of production employees, ergonomists often use the methodology for determination the job strain index. The determination of the job strain index is based on the estimation of six strain variables. An incorrect estimation of strain variables can impair the health of production employee or the company needs to improve the production process. To avoid such inaccurate estimates, is the aim of this work, a developing of a system to measure the six strain variables and to evaluate the stress of the hand objectively. The work starts with a research of sensor gloves that have already been applied for the hand. Subsequently a first system is being developed systematically and demonstrated on a process example. This enables the measurement of all strain variables. The results show that the evaluation of the process and product ergonomics is faster and more accurately.

**Keywords** Hand stress · Hand posture · Job strain index · Strain variables · Sensor gloves · Prototype · SI-Glove

## 1 Introduction

The human hand is constantly in contact with products and is thereby loaded differently. In particular, higher force transmissions, short recovery breaks and wrong hand postures have a high influence degree to the health of the users. A high hand stress may cause typical hand diseases e.g. carpal tunnel syndrome. Especially

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production employees who permanently perform a repetitive activity may be affected.

In most cases Monitoring methods are used to determine the hand stress. This Monitoring methods are based on the scoring of certain stressful situations. Thereby valids low score a low stress. The method LLM-MA (Key Indicator Method for Manual Handling) of [1] and the method RULA (Rapid Upper Limb Assessment) of [2] give a comprehensive illustration of the stress situation of the hand-arm system. But in the most Monitoring methods the level of detail of the hand is limited to few positions. Therefore, JSI (Job Strain Index) by [3] is often determined for the evaluation of the hand stress. With regard to the development of a system to objectify hand stress, this work focuses on the JSI method.

## *1.1 Job Strain Index*

The JSI method was published by [3] and deals with the evaluation of hand stress. Thereto, a manual work is observed for three minutes, and a so-called Job Strain Index (JSI) is calculated. The determination of the JSI is based on the estimate of six strain variables and on the multipliers determined by those. Figure 1 shows a template for determining the multipliers.

The strain variable, intensity of exertion (IE) refers to the maximum effort that can be exerted by a human being [4]. Hand-dependent maximum gripping forces by [5] can help to determine the effort. The strain variables, duration of exertion (DE) and efforts per minute (EM) result from the formulas for the maximum effort. For the estimation of hand/wrist posture (HWP), angle limits for the wrist extension (E), flexion (F) and ulnar deviation (D) are specified. The comparison of the JSI with the limits shows the risks of the hand health.

## *1.2 Sensor Gloves*

In the context of the present work there exist sensor gloves to measure forces when gripping and using products. Table 1 shows some examples of research and development works of sensor gloves. Some works are focused exclusively on the development of new sensor gloves. Some of them are exploring the relations between forces and other variables such as muscle tension [6], handling and feel [7] and the perceived gripping force [8].

To measure the force distribution on the palm most sensor gloves have piezo (-resistive) sensors such as in [9, 15] or [10]. Due to the simple programming and low cost compared to capacitive sensors these are prefered. The force sensors are varying in the number and in the position on the hand and in their form.

To measure the hand posture there exist optical methods and methods in which active sensors are attached to the hand. This work deals with sensor gloves with

| Risk Factor | Rating Criterion | | Observation | Multiplier |
|---|---|---|---|---|
| 1.Intensity of Exertion (IE) | Light | < 10% | barely noticeable or relaxed effort | 1 |
| | Somewhat | 10% - 29% | noticeable or definite effort | 3 |
| | Hard | 30% - 49% | obvious effort, unchanged facial | 6 |
| | Very Hard | 50% - 79% | substantial effort, changes facial | 9 |
| | Near Maximal | >= 80% | uses shoulder or trunk to generate force | 13 |
| 2.Duration of Exertion (DE) | < 10% | | DE = 100 x duration of all exertions (sec) ÷ total observation time (sec) | 0,5 |
| | 10% - 29% | | | 1 |
| | 30% - 49% | | | 1,5 |
| | 50% - 79% | | | 2 |
| | >= 80% | | | 3 |
| 3.Efforts per Minute (EM) | < 4 | | EM=number of exertions ÷ total observation time (min) | 0,5 |
| | 4 - 8 | | | 1 |
| | 8 - 14 | | | 1,5 |
| | 15 - 19 | | | 2 |
| | >= 20 | | | 3 |
| 4.Hand/Wrist Posture (HWP) | Very good | E10°,F5°,D10 | perfectly neutral | 1 |
| | Good | E25°,F15°,D1 | near neutral | 1 |
| | Fair | E40°,F30°,D2 | non neutral | 1,5 |
| | Bad | E55°,F50°,D2 | marked deviation | 2 |
| | Very Bad | E60°,F50°,D2 | near extreme | 3 |
| 5.Speed of Work (SW) | Very Slow | | extremely relaxed pace | 1 |
| | Slow | | taking one's own time | 1 |
| | Fair | | normal speed of motion | 1 |
| | Fast | | rushed, but able to keep up | 1,5 |
| | Very Fast | | rushed and barely or unable to keep up | 2 |
| 6.Duration of Task per Day (DD) | < 1 | | measured or obtained from the staff | 0,25 |
| | 1 - 2 | | | 0,5 |
| | 2 - 4 | | | 0,75 |
| | 4 - 8 | | | 1 |
| | >= 8 | | | 1,5 |
| Job Strain Index (JSI) | JSI < 3 | | Job is probably safe | |
| | JSI > 3 < 7 | | Jobs associated with individual risk | |
| | JSI > 7 | | Job is probably hazardous | |

**Fig. 1** Template for determining the multipliers by [3] based on [4]

active sensors, since optical methods require a complex experimental setup and capture only the movement and posture of the hand [11]. Active sensors are placed in the design as a sensor glove directly to the hand and do not require complex experimental setup [18]. The sensor gloves are often equipped with fiber optic [12], strain gauges [13] or goniometers [14].

## 2 Prototype: SI-Glove

The development of the SI-Glove (strain index glove) was made for a male person of the 50th percentile between 20 and 30 years (see Fig. 2). As glove a model (TouchGrip of UPIXX) in microfibre fabric was used. This remains firm for the fixed position of the sensors on the hand. For the sensors to measure the wrist angle ulnar and radial, a bending sensor (Interlink FSR 408) is mounted on the thumb side of the hand, at the level of the wrist. For the wrist angle palmar and dorsal a

**Table 1** Examples of sensor gloves

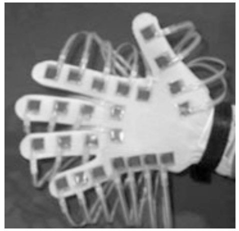
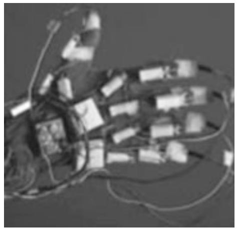
| | | | |
|---|---|---|---|
| Force measurement |  [15] |  [16] |  [17] |
| Posture measurement |  [13] |  [18] |  [11] |

**Fig. 2** Prototype: SI-Glove

potentiometer was used. To this on the back of the glove a sheet metal was sewn to attach the potentiometer. In the forearm a Velcro strip was applied and on the Velcro a sheet metal and a rod was attached.

To measure the force distribution on the palm (thenar, hypothenar, palmar) and on the fingertips were force sensors Interlink (FSR 402, FSR 400) adapted to the preparatory work of [19]. The wiring was led through a slot outwardly towards the back of the hand, so this could cause no hindrance on the palm. All signals of the sensors were lead to the microcontroller (Arduino MEGA 2560). The Arduino has been built with an LCD-Display in a plastic housing. Thus it is possible to wear the evaluation system on a belt.

For calibration the raw data are transferred on the computer in Excel (PLX-DAQ: Parallax Data Acquisition Tool). Approximation functions are derived by the raw data with the using of load cell and angle template. For the validation several measurements by different forces and postures were accomplished. It was shown that the sensors measures are reproducible. For the evaluation of the JSI the measurements were compared with the limit values of Fig. 1. The evaluation was performed in Excel according to the principle of the case distinction. Decisive for the strain variables are mainly maximum forces, angles and times.

## 3 Experiment

### *3.1 Test Procedure*

In the experiment it shall be proven, if by using the prototype, the evaluation of the hand stress is faster and exacter than the classic JSI-method. To show the applicability of the SI-Glove, different strain cases are evaluated using the classic method

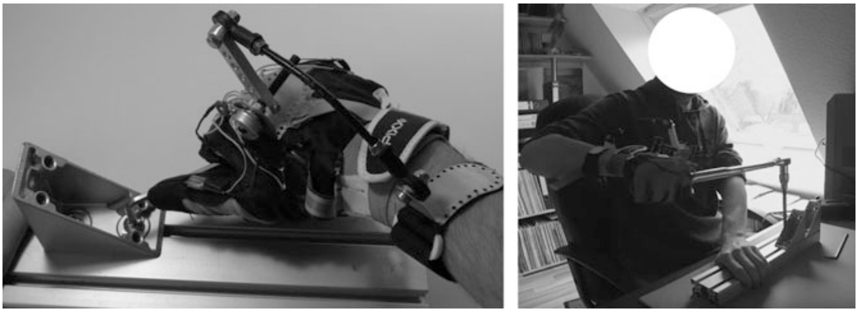


**Fig. 3** Experimental setup. Work steps 4 (*left*) and 5 (*right*)

and compared to the measured JSI. As an experiment angle brackets are assembled on Aluminum profiles in three different variations.

In Fig. 3 the experimental setup is shown. Following work steps were performed:

1. Two slot nuts were placed in the slot.
2. One angle bracket was placed on the slot nuts.
3. Washers were placed on two bolts.
4. Both bolts were screwed into the slot nuts using an allen wrench.
5. Both bolts were tightened with 20 Nm using a torque wrench.

The experiment was performed in three variations to show the function of the SI-Glove and the influence of force and angle on the result. In the first variant the experiment is performed as described above. In the second variant during the tightening of the bolts using the torque wrench, a dorsal flexion of the wrist of about 45° was provoked. Thereby the influence of the hand posture on the strain magnitude should be examined. In the third variant the handle of the torque wrench was grabbed in the middle to increase torque and also the force. Here should be examined the influence of an increased force on hand posture and the intensity of the exertion.

For the purpose of a subjects study the experiments were filmed. One variant took about three minutes. The first variant was performed ten times to analyze the results of the SI-Gloves for measuring a similar task several times.

The subjects were tested independently from each other and were assigned to perform the JSI evaluation using the videos from the three experiments. Apart from the videos the examiners got following information:

1. The speed of work were felt as normal.
2. For the evaluation eight hours of work per day were assumed.
3. The torque was about 20 Nm.
4. The lever in the first and second variant was 29 cm.
5. The lever in the third variant was 15 cm.

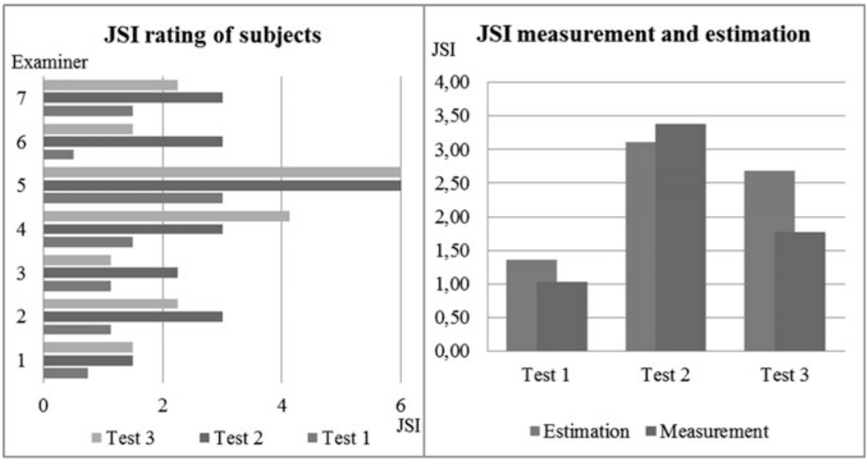



**Fig. 4** Test results. comparison of seven JSI ratings (*left*) and between subjects study and measurement (*right*)

### *3.2 Test Results*

The results of the three experiments are shown in Fig. 4. In the individual JSI rating becomes clear that different estimations exist between the examiners. Examiner 5 for example tends to give higher estimations than examiner 3. The evaluation of the JSI in the subjects study took about 10–15 min for each variant. The measurement took as long as the activity, therefore three minutes.

The comparison between the subjects study (average of individual JSI ratings) and the measurement shows that the estimation is varying a bit from the measurement. The largest deviation arises in the third test variant. The highest hand stress emerges from the extreme hand posture in the second variant.

For the repetition of the first variant a mean for the JSI of 1.055 with a standard deviation of 0.32 was measured. According to this the spread let us expect that the JSI measurements lay at $1.055 \pm 0.32$. The maximum spread is approximately $\pm 0.5$. These results indicate that during the experiments different influencing factors like the grip and strength of fingers, posture of hand and fingers etc. have influences on hand stress.

## 4 Discussion

In summary, with regard to the literature on the measurement of hand stress can be said, that there is no work, which uses a sensor glove to measure strain variables from the JSI method. Very often sensor gloves with force sensors are used to obtain an indication of the power level, without taking the hand posture into account. In some works such as [11], for example, with the sensor glove only the movement or the hand posture, for the purpose of motion capture is measured. Then the measurement data scored with RULA, without taking forces into account. The sensor gloves in the state of the art prove indeed a force reduction or improve the hand posture, but it can't make a statement for the ergonomics. None of the sensor gloves aims solely on the ergonomic quality of a hand-held product.

The developed SI-Gloves gives an effective tool for assessing the hand stress on the basis of JSI method. In addition the examiners don't always have the same expertise and experience with regard to the hand ergonomics and therefore evaluate differently. This demonstrates the benefits of SI-Glove. With regard to the standardization of JSI, arises with the SI-Glove, a potential for application in the industry. The SI-Glove allows the comparison of hand-held products and processes together. A misjudgment of hand stress can be ruled out. The measurement of hand stress takes much shorter than with the classic JSI-rating.

The validation has shown that all sensors provide reproducible measurements for the short-term application. Also, the state of the art shows the use of the piezo (-resistive) sensors. There are now even commercial sensor gloves such as of [20]. However, for the industrial capability and long-term use, the sensors should be examined more closely in order to know limits as power level and duration of sensors. For further development, it is also advisable to integrate a simple replacement of the sensors, because the sensors can be damaged by their sensitivity during continuous use. Other criticisms of the prototypes include obstructing the movement of the hand as well as the outsiders of wired sensors.

With the SI-Glove is shown that strain variables from Monitoring methods may be measured. This also means that other methods such as LMM or RULA can be performed with the measurement method. The high training costs for more accurate results, which is recommended by Steinberg et al. [1], can be reduced with systems such as the SI-Glove. The fact that compressive forces on the hand and finger surface can be measured by the SI-Glove, opens up the possibility of a pressure reduction for comfortable design of hand-held products. The SI-Glove, combined with the work of [19] can be used to assess the pressure distribution and influence factors.

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# User's Capabilities and Limitations Identification in Design Process

**Alejandro Rodea Chávez and Lucila Mercado Colin**

**Abstract** Correct identification of human capabilities and limitations is essential when designing objects, activities or environments that must facilitate the accomplishment of human needs. Expansion of human knowledge provides invaluable input to Design discipline but in practice, such tools, techniques and technologies are quite distant from being directly applicable by the design practitioner, requiring multiple specialists (physiologists, psychologists, anthropologists and others) to translate the findings into useful information for design process. Design process is been permanently modified not only because required objects are each time more intricate or specific, but because the way of gathering necessary to the process incoming data becomes more complex. Describing a wide range of objective or subjective approaches to define User's characteristics should help developing design study programs as well as would be a helpful tool for practitioners of Design to be aware of where and how to look at when dealing with User's characteristics specifications.

**Keywords** Design education · User's characterization · Interdisciplinary · Ergonomics

## 1 Introduction

Designing is a capacity humans have since they imagine situations otherwise inexistent but in their minds. Seen this way, propose a possible divergence is not so difficult.

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There is also the possibility of imagine something and not looking to do it, but if so, it do not always result as expected. So it is possible to change the status quo in other less desired.

Designing professionally in turn, of course requires to have the ability to imagine not just one but several options to modify the reality in another, but seeking to ensure inter alia, such a reality is better to prior one.

Generate alternative scenarios where people can made their activities is a task every designer is prepared for. This requires confronting wide range of variables, constraints and positions in the attempt to establish what should be the desirable future: technical characteristics of objects and spaces involved; economic constraints that limit the extent of penetration in the market of the "new design"[1]; highly complex assortment sociocultural characteristics related to the state that seeks to intervene, as well as the impact on those characteristics after a modification is carried out. All these vicissitudes, which obviously have different indicators and objectives, and are assessed through various optical—ethical, social and environmental responsibilities, are just some of the concerns that mediate design proposals.

Designing professionally therefore involves not the solitary work of a visionary individual, but a group of people who together analyze, discuss and come to the proposal that best can solve a human need.

## 2 Interdisciplinary Approach to Design

The expertise needed to address such a large diversity of variables is only comparable with the range of human needs, and therefore, a design team must always rely on specialists which would give them all the experience and knowledge required throughout the process, from the user's needs investigation, to social, political, technological or any relevant nature to the project, to the characteristics and phases of assessment and feed backing the project itself, since by combining the aforementioned complexity of variables, a design team obviously would require to find and rethink many working assumptions.

In various specialized forums about Design is been described which one(s) are the functions of this discipline; the (industrial) Design "…is the professional service of creating products and systems that optimize function, value and appearance for the mutual benefit of both user and manufacturer" [2].

Moreover, User-Centered Design has been described by indicating that "Too often, systems are designed with a focus on business goals, fancy features, and the technological capabilities of hardware or software tools. All of these approaches to system design omit the most important part of the process—the end user.

[1]The Design Council has developed the report "Innovation by Design" which abound on this economical topic focused on the UK long term economic growth, standing out the research to market contribution of design [1].

User-Centered Design (UCD) is the process of designing a tool, such as a website's or application's user interface, from the perspective of how it will be understood and used by a human user. Rather than requiring users to adapt their attitudes and behaviors in order to learn and use a system, a system can be designed to support its intended users' existing beliefs, attitudes, and behaviors as they relate to the tasks that the system is being designed to support. The result of employing UCD to a system design is a product that offers a more efficient, satisfying, and user-friendly experience for the user, which is likely to increase sales and customer loyalty" [3].

Distinguishable in both definitions is how essential correct identification of human capabilities and limitations is, as well as other human characteristics when designing objects, activities or environments that must facilitate the accomplishment of human activities. Such identification task is performed routinely in the disciplines of human factors, particularly Ergonomics[2] in Design, given the relevance of that aspect in the correct definition of the characteristics that mediate between users and the system (Fig. 1).[3]

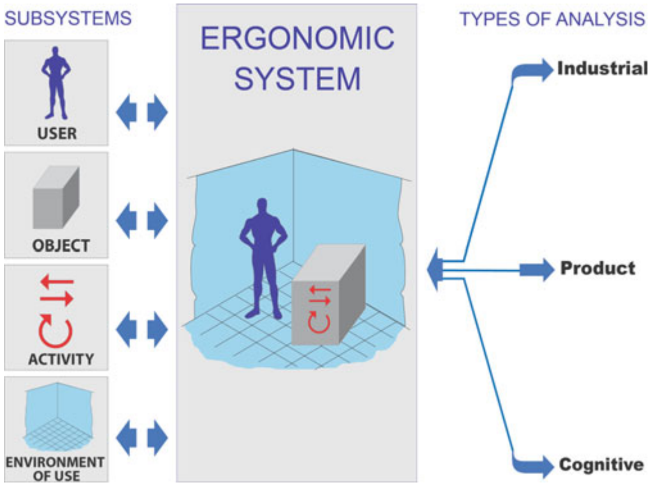


**Fig. 1** Ergonomic System. The *left column* shows the four fundamental elements or subsystems involved on an ergonomic system; these are interrelated on a several types of specific ergonomic analysis

[2]Ergonomics or human factors are the main terms used to refer this interest in human characteristics; There also exist User Centered Design, Usability and so many more terms, all having different postures around the concern of User's needs, capabilities, limitations or expectations related with the overall system.

[3]Referring to the UOAE ergonomic system, where specific Users perform certain Activities, mediated by defined Objects and Environments.

Here User (Human) is seen as one of the subsystems components of the ergonomics analysis, which in this paper is the main objective to argue about how to approach to.

Day to day numerous technologies, methods, strategies and techniques are developed, that in addition to existing ones, intend to facilitate the approach to define who the User is, by detecting and analyzing her or his skills and limitations, ways of thinking and behaving when exposed to various stimuli and circumstances. Jordan expresses how important is to understand the underlying factors when interacting with products, and how Users are "increasingly unwilling to tolerate difficult to use products", arguing it is important "…those responsible for product creation ensure that the requirements and limitations of those using the products are taken into account" [4].

As obvious as it could appear, it worth mention humans are different in a wide range of characteristics and because of it, is mandatory to have a deep overview of Users in order to make assumptions about how they would interact with the overall system (Fig. 2).

Modeling Users then requires describing how they are and, to do it is necessary to observe them, searching about their desires, capabilities, and limitations looking to know them in deep.

Several instruments, techniques and tools are been developed to achieve those goals, leading to an expansion of human knowledge and providing invaluable input to designing (among other beneficiaries disciplines); but in practice, such tools, techniques and technologies are quite often distant from being directly applicable by the design practitioner, meaning it requires multiple specialists (physiologists, psychologists, anthropologists and others) to translate and apply the findings into useful information for design process.

The referred variety of methods or technologies is huge; some of which are relatively simple in its application (not easy) such as anthropometric measurements, interviews, or applying questionnaires, have been assimilated by most designers, requiring of them more rigorous training to be able to plan, develop, implement or interpret it, and to be aware of its scope and limitations (Fig. 3).

Different situation would happen when involving those technologies and methods that uses sophisticated equipment such as eye-tracker or biofeedback

**Fig. 2** Different users, different characteristics

**Fig. 3** Anthropometric measuring, interviewing and questioning tasks

**Fig. 4** Examples of electrodynamometers, thermal cameras, eye tracker interfaces and information displays

systems (both tools mainly focused on gathering physiological data), or when other research methods like ethnography (focused on cultural or Sociological Aspects) are used by designers as rich data sources, but it require specialized training and knowledge, so different to the skills promoted in design schools (Fig. 4).

> Suppose an educational psychologist wishes to use eye tracking could provide to evaluate a new software package designed to support learning to read. She may have an excellent idea as a starting point, and some understanding of the kind of results eye tracking could provide to tackle her research question, but unless she and the group around her are also adept to computer science, it is unlikely she will know how the eye movement data she collects is generated: How raw data samples are converted into fixations and saccades using event detection algorithms, how the different representations of eye movements data are calculated, and how all the measures of eye movements relate to these process [5].

Because this reasons, it is essential to train designers (and many other discipline practitioners) trans disciplinarily, providing this professionals not only inherent skills for designing, meaning with it of drawing, prototyping, sketching and all the well-known skills taught at any design school, but to interpreting specialized data provided by other fields of knowledge, and in best cases, to enable be part of the teams carrying out necessary studies for obtaining relevant data in a given design project.

This is easy to say, but how difficult could be implementing it? Depending on several factors like the country where the school belong, and the specific history of it, Design schools are joined mainly to two knowledge areas: arts and engineering. And because of it, focuses its efforts in a set of concepts feasible to assimilate and use from this areas.

When inquiring about Users as an ergonomic subsystem, several disciplines come together to enlighten designers about capabilities, limitations, desires, expectation, fears, and so on, but those are not always neither on engineering nor arts. Humanities as well as biological fields of knowledge (or even economical ones) are also determinant sources when searching about users.[4]

[4]To apply the term User has been questioned since it refers a "hole" human being, who has several capabilities, expectations, beliefs and a list of characteristics much more greater than just being user of a thing. Here is stated the term User is a more precise one, because it doesn't take away the humanity of a person, neither understate any of his or her characteristics, but emphasizes is the human being who uses something—and not any human being—; as when using the terms driver, cooker or teacher referring to persons who do concrete tasks or have specific skills.

Some human biological characteristics are gathered by different technical equipment or methods as biofeedback which could sense (and feedback) several biometrical signals as electromyography (EMG) or electrocardiogram (EKG), electroencephalograms (EEG) or neurofeedback, hart rate, body temperature, skin conductance, blood volume pulse (BVP), respiration and so on. There are also oximeters, spirometers, dynamometers, and many other sophisticated equipment that gathers biological and physiological signals.

The list is huge, and of course using any of that equipment requires profound knowledge and training, lacking in design school programs.

Meanwhile, when dealing with user's cognitive or emotional dimensions, some of the referred equipment could be used to, via correlating diverse indicators, infer what a person is experiencing.

It is fair to say—without the intension to minimize the aforementioned reasons—that of course there are instruments to approach users that have been developed from inside the Design discipline, such the Experience-Context Enquiry Design Tool (ECEDT), reported to be helpful in the design of user–product interactions by enhancing the understanding of "four sources of human experience influencing people's understanding of product usability; these comprise: familiarity, episodic experience, experience from cultural background, and experience from expert domain" [6].

Even though, specialists who have developed this and another Design tools, strategies or principles have supported their arguments on physiological, biological and other kind of knowledge, interpreting it on what designers could use in a fluent manner.

There are also other ways to approach user's characteristics, like semiotics or analysis of language (non-verbal techniques), useful to infer from the kind of gestures or behavior a person does, the emotional load or subjectivity input in a communicational level.

This shallow overview of approaches to human characteristics, from biological to physiological or behavioral ones, is done in order to aware how to apply it across the Design process and with it, realize how important could be Design studies should approach to those techniques.

By mapping a spectrum of users characteristics, capabilities, limitations and experiences, it will be enhanced the pertinence of approaching different technologies, methods, strategies and techniques useful to design process.

## 3 Discussion

The design process is been permanently modified not only because products, messages or services required are each time more intricate or specific, but because the way of gathering incoming data—necessary to the process—becomes more and more complex (i.e. formulating or identifying user's needs in early stages, modeling or rapid prototyping design concepts in order to be tested and iterated, or developing global evaluations of final products, messages or services at the end of the process). Therefore, describing a wide range of objective or subjective approaches to define User's characteristics should help developing design study programs as well as would be a helpful tool for practitioners of Design to be aware of where and how to look at when dealing with user's characteristics specifications.

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# Increasing Sustainability by Improving Full Use of Public Space: Human Centred Design for Easy-to-Walk Built Environment

**Erminia Attaianese**

**Abstract** The paper presents the application of Human Centered Design Methodology for easy-to-walk built environment, meaning for easy-to-walk a place where features and finishing of built environment are selected to give a path really supporting all the scopes of different walking users, in condition of comfort, safety and pleasantness. Overcoming current research, focusing falls studies and showing a separation among biomedical, psychological and technical disciplines, the paper shows an integrated approach where technical requirements for easy-to-walk built environment (i.e. dimensions, flooring materials and constructive characteristics together with climatic, acoustic and illuminations conditions) are derived from the observation of different users' ability and limitations. To do that mobility models have been defined in order to consider walking personal attitude and habits; age of the users and their physiological and pathological modifications; movements, perception and cognition in temporary and permanent disabilities; motivations and life styles of users.

**Keywords** Human factors · Mobility models · Walking · Social sustainability · Public spaces

## 1 Introduction

A recent mode of thinking about sustainability is that the three spheres of influence, environmental, social and economic, are represented equally, by means of an 'overlapping circles' model [1]. This model reflects the increased awareness gained by social sustainability as a fundamental component of sustainable development to encompass human rights, labour rights, and corporate governance, since future generations should have the same or greater access to social resources as the current generation [1, 2].

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With respect to the built environment social sustainability has been defined as a process for creating places able to promote wellbeing, respecting what people need from the places they live and work: in other words places being able to sustain human social and cultural life [2, 3].

Thus generating a harmonious living place, reducing inequalities and increasing quality of life in general, have been identified as social goals for urban environment.

To reach these goals availability and accessibility of social infrastructures and job opportunities, townscape design and preservation of local characteristics and identity, ability to fulfill psychological needs have to be pursued [2].

More recently literature indicates that the emerging measures for social sustainability include health and well-being, safety and security, access to facilities and amenities, participation and social interactions [3], all of them proveding the whole of conditions for a full use of built environment.

## 2 Full Use of Built Environment as Sustainability Indicator

Equity of access to services may be considered as one of the indicators of social sustainability, since it contributes to a positive condition for individuals to thrive with equal access to opportunities for individual development [1]. Given that it is widely interpreted as mean achieving social equity and inclusiveness, from a design perspective, social sustainability requires to ensure inclusion by considering needs of underrepresented groups of population [4].

For this reason built environment, particularly social infrastructures [5], needs to be designed and maintained in order to allow optimal use by the greatest extent possible of people, letting each one to do the activities he wants to do, without the need for adaptation or specialized design.

To do that the three areas of Accessibility, Usability and Safety are involved; all of them can be seen as specialized facets of Ergonomic Design [6].

United Nation recognized the importance of accessibility to the physical, social, economic and cultural environment, to health and education and to information and communication, in enabling persons with disabilities to fully enjoy all human rights and fundamental freedoms [7].

But in the context of international standards a broader concept of accessibility emerges addressing the full range of user capabilities, not limiting to users who are formally recognized as having a disability [8]. Actually the idea that an accessible environment needs a specialized barrier-free design gradually changed addressing broader scope of accessibility and user-friendliness, for diverse users throughout a lifetime [9]. Moreover literature and international standards and legislation affirm accessibility is one of the main quality of public spaces [3].

## 3 The Social Value of Public Space

Public spaces play a fundamental function in the social life of communities, since they act as a self-organising public service, a sort of a wide social infrastructure, a shared resource, experienced by people every day in different ways [10, 11].

They, by nature, are socially inclusive and pluralist; inclusive public spaces are seen as a spatial dimension of social sustainability [12].

A public space can be described as a space concerning the people as a whole, open to all, accessible to or shared by all members of the community, provided by the public authorities for the use of people in general [13]. We can see it as the common ground where people carry out the functional and ritual activities that bind a community, whether in the normal routines of daily life or in extraordinary situations, for private purposes, as buying or selling things, or for simply finding an existing place or, also, for public intention, for example when people demonstrate against something in the street.

Streets, squares, and parks are dynamic places giving form to the flow of human exchange; they are essential elements of settled places and routines of work and home life, providing the channels for movement, the needs of communication, and the common grounds for play and interact [14], since a combination of a wide range of different human activities with different scopes, both moving and stationary, are supported by public spaces when they result lively and successfully [15].

Public spaces are utilized by users with a wide range of motivation and goals, which may induce users to feel several different emotional status such as rush, disorientation, anxiety, excitation, waiting, relax, and so on. Ghel identifies three distinct categories of activities taking place in public spaces, qualified as necessary, such as transport and business activities, that are generally purposeful and take place at all times; optional, regarding what we like to do, such as recreational activities in urban spaces, that may be frequently spontaneous; and social ones, covering a wide range of civic activities concerning both when people are passively present, such as attending a concert or other open entertainments, both when they incur in unplanned and unexpected meetings with other people [16].

Walkability is today one of the main concept associated to public spaces. It is defined as the extent to which the built environment is friendly to people moving on foot in an area [17].

## 4 Pedestrian Walking in Public Space

Walking is a fundamental activity of human life, especially in public spaces. It results more than a mode to transport or a means to cover distances [18], although one of the most common urban strategies for sustainable mobility is today favouring people transit on foot [19]. It may be seen as a social process in which people constantly meet, see and hear other people, and an complex activity from which people can shift to other types of different activities [18]. Walking is the result of both physical and mental stimuli, due to not only the contact of the body on the soil, but particularly to the whole of human perceptions solicited from the environment in different situations, including physiological, physical, social and psychological reactions.

According to Ovstedal comfort for pedestrian may be defined as a positive emotional reaction to walking environment, and factors that may influence it are related to thermal, visual, acoustic, tactile, smells, air pollution and allergens, easy to move and feeling of security [19].

Walking, as physical walk and mental walk, is assumed as the main tool people have to experience a place allowing a comprehensive perception of space's multiple dimensions [20].

Each person has its own personal walking style, coming from age, motor, sensory and cognitive abilities, its own physical structure, sex, and personal motivation moving in the space.

So paths and walks are particularly critical element, for the possibility they may have to influence the walking activity in different ways. First of all they cause slip and trip accidents, since people are often busy involved in many simultaneous tasks (e.g. walking, orienting, interpreting and understanding places, getting information, holding/bringing stuffs, checking time, etc.), or because paths are made of elements which technical performances may rapidly vary and/or decay by usury, dirt, weather factors, etc.

Moreover by the configuration of public space, particularly pedestrian walkways, may depend not only the effectiveness and efficiency of people activities, but also the sense of safety, security and comfort perceived in built environment [20, 21].

## *4.1 Observing Human, Technical and Environmental Factors*

Although it is almost entirely automatic, locomotion is a very complicated task, laboriously acquired, requiring to coordinate every instant a dynamic balance problem (movement) with a static balance one (posture), and involving nervous and musculoskeletal systems, with cognitive and emotional personal reactions.

In these framework optimizing walking conditions in public spaces for the wide range of users, became crucial for improving social sustainability through the full use of built environment.

Slip causes for pedestrians can be connected to various factors, working singularly or combining with others until the critical point of "not balance". At the origin of an accident, there are always 3 factors: a subject susceptible to fall, a factor provoking the accident and an environment that favouring the event [22].

*Human factors*

Each individual moves its barycentre in a personal way, propping the foot mainly on the heel rather than on the sole, toward the inner or the outer of the foot; people can be more attentive or easy to disrupt, could make long or shorter foot-steps, so that some people can be stronger exposed to the fall risk than others.

Of course, also shoes affect people ambulation, depending on the hell height and style, sole material, wear and tear state, etc., can reduce the adhesion between the foot and the floor and induce falls.

*Technical factors*

First of all, flooring conditions have to be considered: discontinuous or rambling surfaces, carpets and doormats, wet, oily, polished or dirty surfaces, thresholds, not visible steps, inadequate reflectance, abrasion, friction coefficients as well as flooring colour and texture can all provoke slip or trip. Moreover, these technical characteristics are modified by flooring use condition: some spaces will be mainly used by intense pedestrian flows, some other ones in a more static way, standard walking path can be crossed by "informal" shortcut impeding main movement flows.

Also exposure to dirt is a significant variable: it implies different wear and tear levels as well as different coefficient of friction for the same flooring surface.

Finally we have to mention finish floor characteristics affecting the fall risk and the walk pleasantness: a shiny surface, even if performing an adequate friction, will be perceived as slippery, and subjects will instinctively alter their barycentre, increasing the fall risk; besides that, also decorative pattern in flooring surfaces has to be taken into account, since a wrong combination of colours and shapes can alter visual perception and favour fall accidents.

*Environmental factors*

Lighting, acoustic, thermal and climatic conditions, as well dimensional, functional and layout aspects influence the quality of walking conditions. Many aspects can decrease people walking capabilities such as low lighted or too brightened places, particular climatic situations (e.g. rain or wetness) conditioning floor characteristics, the incidence of noises, excessive path length and inadequate signals. All modifications of these systems by humans psychological and physiological factors and/or technical and environmental ones can bring to dangerous functional alterations of the walking movements.

# 5 Human Centred Design for Easy-to-Walk Built Environment

## 5.1 The Integrated Approach

According to human-centred building design process, user-related requirements for easy-to-walk performance of built environment are elicited by a sequence of cyclical steps, starting from definition of users' profiles and clusters setting, to task scenario identification and sub-task descriptions according to users' goals, in order to tailor users' requirements and define architectural details [23].

We can define easy-to-walk built environment as a place where features and finishing are selected to give a pathways really supporting all the scopes of all different walking users, in condition of comfort, safety and pleasantness.

Current studies about walking are focused on slips and trips and falls, showing an increasing integration among biomedical, psychological and technical disciplines [24]. In general, researches are conducted on walk ability in the physician ambit, and are oriented to the monitoring of human psycho-cognitive conditions during the walk, in order to investigate how to improve health and well-being of users [25]. On the other hand technical studies are mainly focused on flooring materials experimentations, in order to identify friction coefficients, without considering human needs in terms of capabilities and limitations [26].

The integrated framework starts from the study of human/behavioral factor in order to understand human characteristics and needs related to a specific use in walking task. Since the users of a public place have to be expected as inclusive of all kind of users' categories, the schematisation of the whole of users in a set of users' categories has been necessary in order to accurately analyze each specific need or expectance "for all", reducing the risk to discard or undervalue some aspects that could be determining for the study about pedestrian walking [27].

## 5.2 Users Mobility Models, Users Walking Needs and Walking Requirements in Public Spaces

A particular attention has been reserved to users' profiles and clusters setting step. Each user profile has been defined considering a group of specific aspects: personal factors (age, sex, physical characteristics, etc.), cognitive factors (intellective abilities, skills, motivations, etc.) and behavioural factors. From this initial set of data the whole of physical abilities and limitations, intellective abilities, personal habits and social lifestyle of users has been elicited. This sort of user survey requires techniques and data collection methods to be applied, both analytic and empiric, so that by the wide range of data gathered all users needs has been truthfully depicted.

Physical ability, sensorial and behavioural characteristics have been selected as criteria for walking phenomena observation and users clustering. Particularly a wide range of pedestrian people as been detected. Elderly peoples, children, users with wheel chair, pregnant women, parents with trolley and different typology of temporarily disability have been analyzed by a physiological and/or pathological point of view, in order to define technical components affecting the quality of walking task addressing specifically user's mobility models needs (Table 1).

Under this point of view, different categories of pedestrian, such as elderly people, children, motor-disabled peoples, can express, each one, a specific habit or skill in walking, clearly distinguishing needs of one user category from the others, or express common needs, because they express similar mobility features.

On the other side, for what concerns motivation, a good example of differences among users is given by someone is walking in a rush thinking to an important work commitment or by another peacefully walking for fun. These conditions too were analyzed in relation to their impact on mobility, to define users clusters by mobility models.

Mobility models synthesize the different ways in which real pedestrian users walk, in habitual and exceptional situations, considering their physical ability, sensorial and behavioural characteristics. In relation to each mobility model, 11 recurring user walking needs have been specified.

Than 45 technical requirements of flooring and pedestrian walks for easy-to-walk built environment relating to user needs resulted, pointed in 72 specifications details (quantitative when possible).

**Table 1** User mobility model in relation to clustering criteria

| Clustering criteria | User mobility model |
|---|---|
| Physical ability | Haltered pace |
| | Walking with stick or crutch |
| | Moving with wheelchair |
| | Difficulty in keeping balance |
| | Low fatigue resistance |
| Sensory ability | Partial visual impairment |
| | Heavy or total visual impairment |
| | Haltered color perception |
| | Partial auditory impairment |
| | Heavy or total auditory impairment |
| | Fear of falling |
| Behavioral characteristics | Unknown place |
| | Brisk walk |
| | Slow walk |
| | Weight/luggage manual handling |
| | Weight/luggage handling with trolleys |
| | High heel or special footwear |

Recurring users needs are resulted:

- Need for walking dragging on the flooring surface a feet or foot
- Need for walking shifting the body load on an extremely small interface between feet an flooring surface (cane, crutch, tripods, shoes heels)
- Need for favouring wheels moving (wheelchairs, strollers, trolleys, etc.)
- Need for finding support along the path
- Need for avoiding or being protected from environment stimuli inducing dizziness or loss
- balance
- Need for avoiding high and persistent physical loads during the walk
- Need for avoiding high and persistent visual loads during the walk
- Need for recreation during the walk
- Need for weathering protection
- Need to recognize and understand features paths and wayfinding, through the different perceptual/sensory channels.

**Table 2** Relevant walking requirement list

| Walking requirement | Type of requirement |
|---|---|
| Environmental explicit information adequacy | Technical |
| Spatial and functional implicit information adequacy | Spatial/functional environmental |
| Chromatic and textural finishing of technical elements adequacy | Technical |
| Paths dimensions adequacy | Spatial/functional |
| Morphology and altimetry adequacy of walking surfaces | Spatial/functional |
| Texture of walking surfaces adequacy | Technical |
| Materic integrity of paving | Technical |
| Atmospheric agents protections facilities and equipment availability | Technical environmental |
| Recreation and commercial facilities and equipment availability | Environmental |
| Mobile facilities availability (escalators, conveyor belts, etc.) | Technical environmental |
| Resting facilities and equipment availability (seating, food, toilets, etc.) | Technical environmental |
| Stable supports and aids elements availability | Technical environmental |
| Tactile and visual pleasantness technical elements and equipments | Technical |
| Paving flatness | Technical |
| Paths layout and walking surfaces regularity | Spatial/functional |
| Chemical agents and stains paving resistance | Technical |
| Footprint paving resistance | Technical |
| Slip paving resistance | Technical |
| Static and dynamic loads paving resistance | Technical |

Walking requirements of flooring and pedestrian walks have been elicited by recurring users needs, as they embody how walking surfaces and pathways need to be performed to address the wide variability of pedestrian ability, capability and behaviors, expressing, qualities and quantities terms, conditions for optimizing public walking environment. They concern technical, environmental and spatial/functional aspects of walking environments, detailed in a list of 72 specification (i.e. forms, dimensions, material, textures, colours, parameters, etc.)

The most relevant walking requirements is listed below (Table 2).

## 6 Conclusions

It is quite generally acquired that inclusive public space is a spatial dimension of socially sustainable development.

According to current literature about walking [28], Human Centred Design methodology applied to easy-to-walk built environment confirmed that user walking needs are affected by more than one aspect of pedestrian comfort, especially in public spaces.

Walkability is today one of the main concept associated to public spaces [29], and expressing the extent to which the built environment is friendly to people moving on foot in an area, it could be seen as one of the most relevant aspect of public spaces accessibility. In fact accessibility, seen in a broad sense, indicates the user-friendliness of public spaces, and since people use public spaces mainly walking, it expresses how walking environment in public spaces address the wide range of diverse people abilities and capabilities throughout a lifetime, allowing full use of this special social infrastructure.

The need of people to move effectively and effectiveness, in a pleasant psycho-physical condition, is preminent in public spaces and walkability results as a basic requirement of built environment. But variability of pedestrian scopes and motivations, in association to the great number of different environmental and technical factors, are determinant for quality of people walking conditions, because they affect personal abilities, capabilities and walking styles of pedestrians, inducing physical and emotional reactions from which well-being of pedestrians actually depends.

Safety and security are fundamental performance of easy-to-walk environment, since pedestrian sensations of insecurity and unsafeness bias comfort perception, conditioning personal walking balance and movement; this perception may influence pedestrians in accepting and/or refusing a public area.

Also the easiness to find the way is an important quality, because a place supporting a sense of familiarity when walking is perceived as safe and comfortable, inspiring a confident fruition of built environment by pedestrian.

Finally visual, acoustic and thermal comfort, with air quality perception, are crucial in walkable environment of outdoor public spaces, since they are mainly due to the weather, and to availability of shelters for protection from the weather conditions and sitting structures.

The integrated approach impresses by the application of Human Centred Design methodology permitted to analyze the complex issue of walkability in public spaces in a wide frame, bridging human factors with technical and environmental factors, in order to identify qualities and detailis of walking environment more fitting diverse needs of public spaces pedestrians.

To synthesize the different ways in which all real typologies of pedestrian users walk, in habitual and exceptional situations, considering physical ability, sensorial and behavioural characteristics, a set a mobility models have been defined, in relation to which 11 recurring user walking needs have been specified. Finally 45 technical requirements of flooring and pedestrian walks for easy-to-walk built environment have been resulted, pointed in 72 specifications.

As a result the list technical requirements and related quail-quantitative specifications provide a set of criteria to design or assess an easy-to-walk public spaces, meaning for easy-to-walk a place where features and finishing of built environment are selected to give a path really supporting all the scopes of different walking users, in condition of comfort, safety and pleasantness.

Moreover an unexpected result is the set of users mobility models that, clustering the wide diversity of pedestrians in public spaces by detecting and grouping similar mobility features, could be helpful to identify other users needs, and technical requirements, in different design contexts.

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# Ocular Movement Characteristics to LED Lights with High Luminous Intensity

**Atsuo Murata, Tomohisa Takamoto and Makoto Moriwaka**

**Abstract** The ocular movement characteristics to LED lights with high luminous intensity were explored when viewing such LED lights using a belt conveyer equipped with such LED light with high luminous intensity. The ocular movement characteristics such as blink duration, blink frequency, and PERCLOS70 were investigated as a function of LED color and luminous intensity. The blink duration consistently tended to increase with the increase of luminous intensity for all colors of LED. The blink frequency tended to increase under the high luminous intensity for both red and white LED which have higher wavelength. As for green LED, the blink frequency was not affected by the luminous intensity. Contrary to the case of red and white LED, the blink frequency of blue LED tended to decrease under the high luminous intensity. PERCLOS70 of red, white, and green LEDs tended to increase with the increase of luminous intensity. In this manner, the ocular movement characteristics of blue LED could be indicated.

**Keywords** Ocular movement · Blink duration · Blink frequency · LED light · High luminous intensity

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## 1 Introduction

There a lot of studied on the technical improvement of LED (Svilainis [1]; Huang et al. [2]; Muthu et al. [3]). It is expected that LED Lighting Improves visibility and also saves money for power plants, etc. LED Lights are also expected to improve snowplow vehicle visibility or visibility under the low visibility conditions such as fog.

Holzman [4] suggested the advantage of blue LED in a variety of applications related to human and environmental health. Palmai et al. [5] investigated the visibility of LED light with low luminous intensity. Liou et al. [6] attempted to make the LED display sign be more legible under high illuminative environments and to avoid the observers feeling dazzling glare under low illuminative environments by using the following experimental factors: ambient illumination, luminance contrast and character form. They demonstrated that the farther the distance was, the clearer the legibility was. Higher ambient illumination could effectively reduce glare perception to LED display signs. In this study, the luminous intensity of LED ranged from 1033 to 3100 cd/m2. The two forms of character did not affect the comfort and glare perception.

The high luminous intensity LED is used to test the quality of a variety of foods and find out abnormal one for enhancing food safety. It is empirically reported from workers involved in such a task that LED with high luminous intensity more than 15000 lx leads to high visibility of tested food and ease to find abnormal food. However, this has not been scientifically explored thoroughly. The ocular movement characteristics to LED lights with high luminous intensity were explored when viewing such LED lights using a belt conveyer equipped with such LED light with high luminous intensity (in more detail, see Fig. 2). The ocular movement characteristics such as blink duration, blink frequency, and PERCLOS70 were investigated as a function of LED color and luminous intensity.

## 2 Method

### *2.1 Participants*

Twenty four participants aged from 22 to 24 years old (22 males and 2 females) took part in the experiment. All of the participants hand no disorders in their visual system. For eight male participants, the measurements were repeated three times in order to confirm the reproducibility of measured data. All signed the informed consent after being briefly explained on the contents of the measurement.


**Fig. 1** Apparatus for measuring ocular movement and PERCLOS70

## 2.2 *Apparatus*

The ocular movements were measured using Drowsimeter (Phasya) (see Fig. 1). The LED lights emitted upward from a food testing belt conveyor system SUMCON-MJ-Q (Sum Tech Innovations Co. Ltd.) (see Fig. 2) were used to explore the response of the participants to LED light with different colors and luminous intensity.

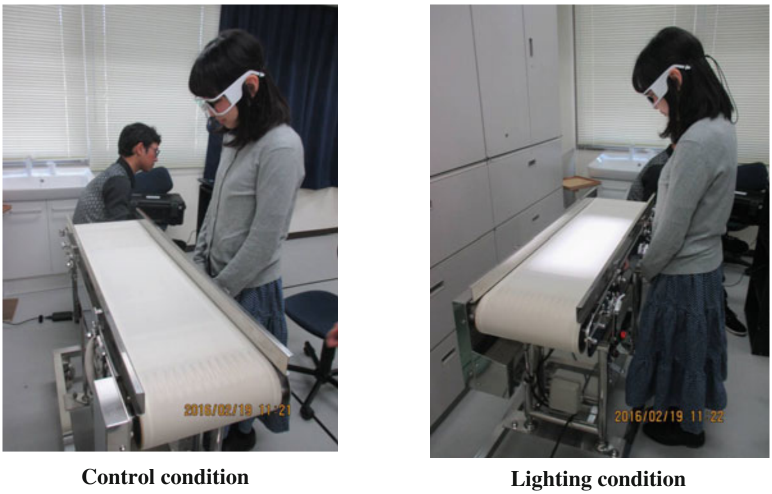



**Fig. 2** Photos of measurements under control and lighting conditions SUMCON-MJ-Q (Sum Tech Innovations Co. Ltd.)

### 2.3 Design, Task, and Procedure

The experimental factors were the color of LED (red, green, blue, and white) and the luminous intensity of LED (low condition: about 3500 lx, high condition: about 17500 lx). All were within-subject factors. A total of eight measurements were conducted for each combination of color and luminous intensity. It took about four minutes to carry out one measurement. The rest interval between measurements was not set except when participant required the experimenter to give him or her a break. The order of performance of eight conditions was randomized across the participants. It took about 45 min to complete all of eight measurements.

One measurement consists of the following process: (1) calibration of Drowsimeter, (2) measurement under the control condition (without LED lighting stimulus) [see Fig. 2 (left)], and (3) measurement under the lighting condition [see Fig. 2 (right)].

The participant was required to stand in front of a conveyor system, to gaze at the center on the surface of the conveyor system, and not to move during the measurement. Before measurement, Drowsimeter was calibrated for about one minute. After the completion of calibration, the one-minute measurement under the control was conducted. The measurement under the lighting condition was uninterruptedly conducted for two minutes. The procedure is summarized in Fig. 3.

### 2.4 Ocular Movement Parameters

PERCLOS70 is explained in Fig. 4. PERCLOS represents the ratio of the time when the open of the pupil was less than 70 % of the calibrated pupil size over 60 s.

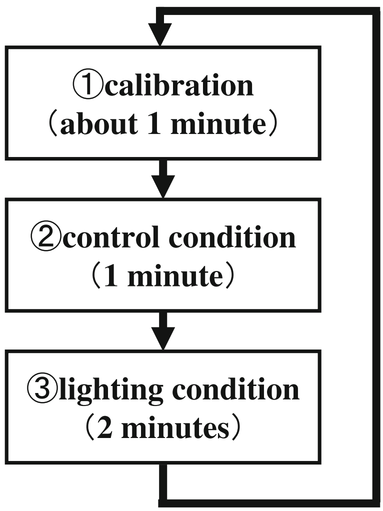
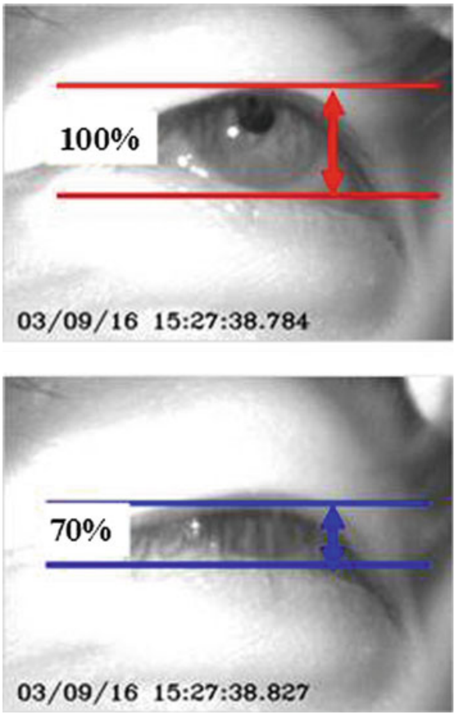



**Fig. 3** Measurement procedure

**Fig. 4** Explanation of PERCLOS70




The upper part of Fig. 4 corresponds to the image of the pupil used as a baseline of the pupil size (100 %). The blink duration was defined as blink duration averaged over 60 s. The blink frequency was defined as blink frequency averaged over 60 s.

## 3 Results

### *3.1 Blink Duration*

The blink duration is plotted as a function of color and luminous intensity in Fig. 5. In Fig. 6 (left), the blink duration is compared among four LED colors. The blink duration compared between high and low luminous intensity is shown in Fig. 6 (right).

### *3.2 Blink Frequency*

In Fig. 7, the blink frequency is compared among four LED colors and between high and low luminous intensity. The blink frequency is compared among four

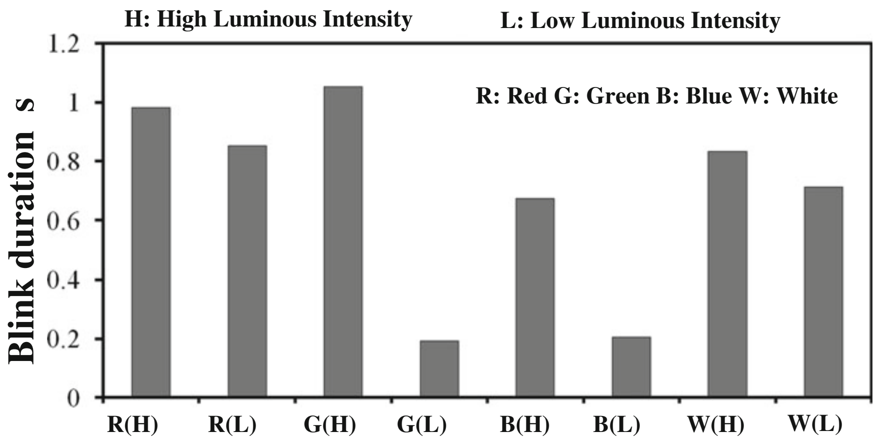



**Fig. 5** Blink duration as a function of color and luminous intensity

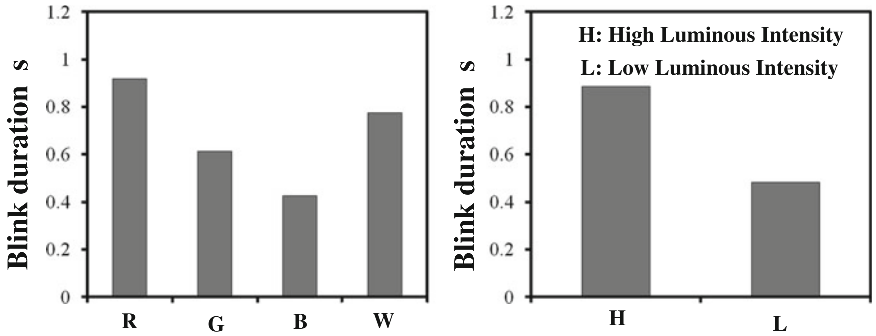



**Fig. 6** Blink duration as a function of color (*left*) and luminous intensity (*right*)

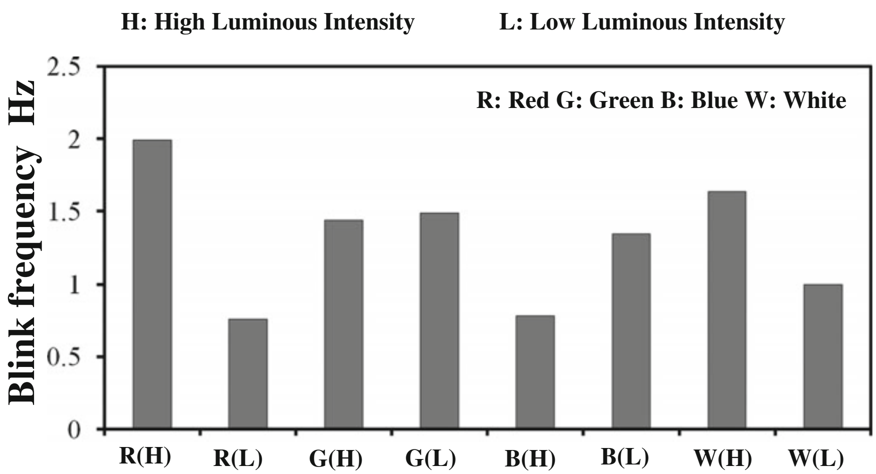



**Fig. 7** Blink frequency as a function of color and luminous intensity

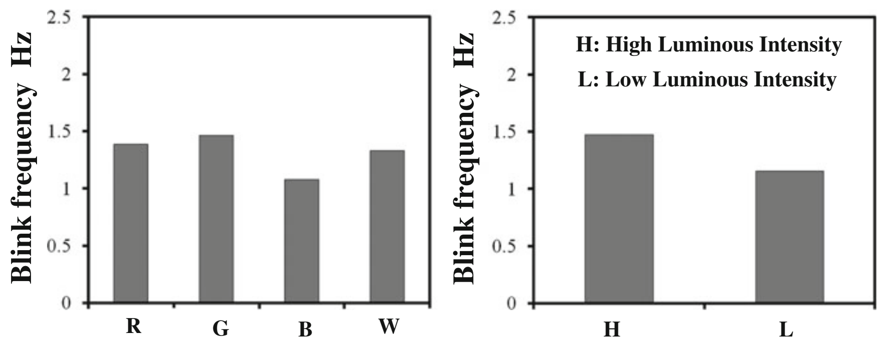



**Fig. 8** Blink frequency as a function of color (*left*) and luminous intensity (*right*)

LED colors in Fig. 8 (left). In Fig. 8 (right), the blink frequency is compared among high and low luminous intensity conditions.

### 3.3 PERCLOS70

PERCLOS70 is plotted as a function of LED color and luminous intensity in Fig. 9. PERCLOS70 is compared among LED colors in Fig. 10 (left). In Fig. 10 (right), PERCLOS70 is plotted as a function of luminous intensity.

### 3.4 Reproducibility of Ocular Movement Parameters

As a result of checking the measures data using ANOVA (Analysis of Variance), no significant differences were detected among three repetitions. This indicates that the measured ocular movement parameters are reproducible.

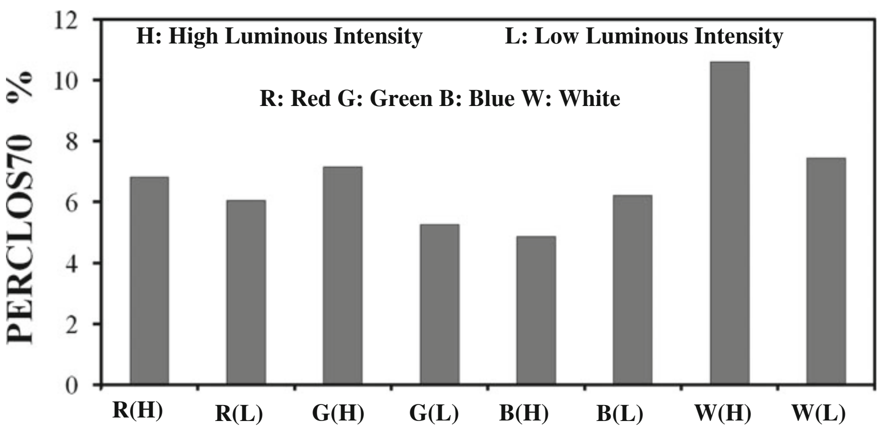



**Fig. 9** PERCLOS70 as a function of color and luminous intensity

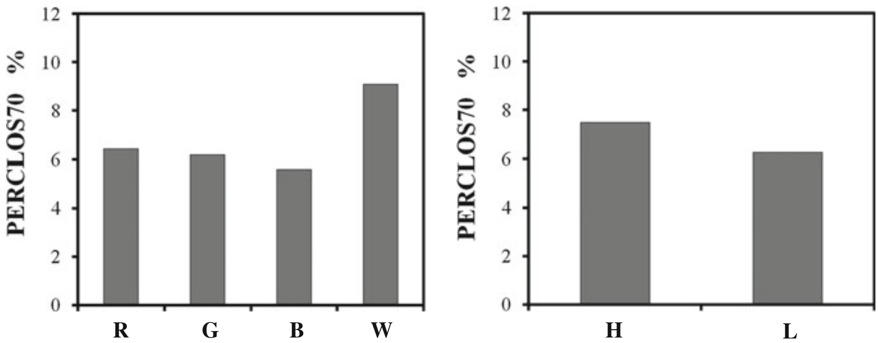



**Fig. 10** PERCLOS70 as a function of color (*left*) and luminous intensity (*right*)

## 4 Discussion

Human's eye movement (or ocular movement) might be classified into reflective eye movement, voluntary eye movement, and involuntary eye movement. In this experiment, the measured ocular movement is mainly based on the response to LED stimulation. Therefore, it is speculated that the ocular movement mechanism is based on reflective one.

The following common features were observed. For all LED colors, the blink duration tended to be prolonged with the increase of the strength of the stimulation. In other words, the blink duration tended to increase with the increase of strength of stimulus irrespective of wavelength of LED. This might indicate that the blink duration is increased as a result of reflective response to strong stimulation. Generally, taken from the viewpoint of involuntary ocular movement, the increased blink duration might be indicative of the increase of drowsiness. The drowsiness level of all participants was very low in this study since we selected only highly aroused participants. Therefore, it must be noted that the increased blink duration is not due to the increased drowsiness (decreased arousal level) but due to the response to stronger stimulus (in this study, high luminous LED).

The following different features were also observed. As for color LED other than blue LED, PERCLOS70 tended to increase when the stimulus was strong (high luminous intensity). This phenomenon might also reflect the reflective response to a strong stimulus.

As for the blink frequency, the tendency differed among LED colors. The blink frequency of red and white LEDs tended to increase when the luminous intensity was high. The blink frequency of green LED was not affected by the strength of luminous intensity. The blink frequency of blue LED tended to decrease when the luminous intensity was high. The results might be modeled as shown in Figs. 11, 12.

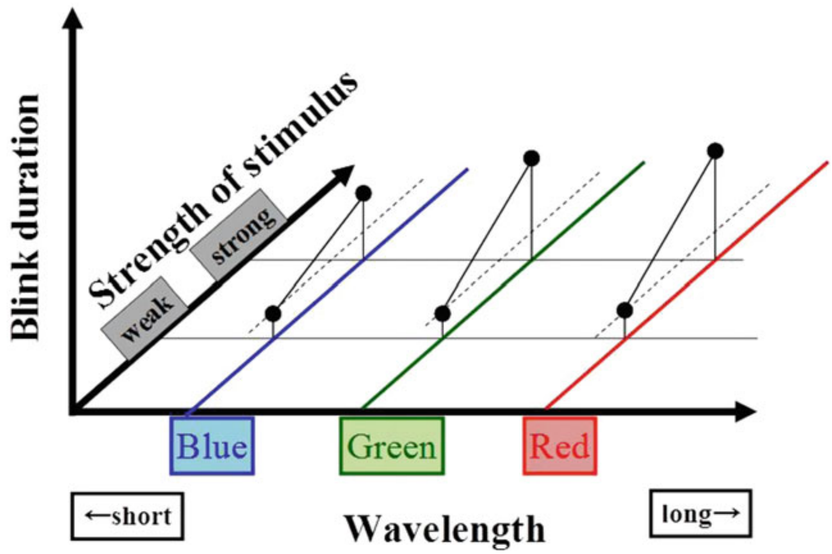



**Fig. 11** Effects of luminous intensity of LED on blink duration for each color

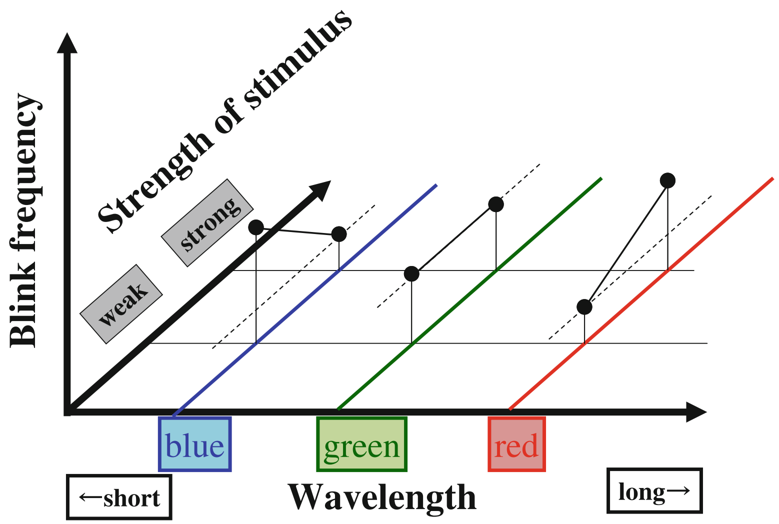



**Fig. 12** Effects of luminous intensity of LED on blink frequency for each color

Concerning blue LED, it might be hypothesized as follows. The increased blink duration is compensated for by the decrease of blink frequency with the increase of strength of stimulus (see Figs. 11, 12). This hypothesis might support some advantages of blue LED over other LEDs reported by Holzman [4]. The hypothesis should be further verified in future research.

## 5 Conclusions

The ocular movement characteristics such as blink duration, blink frequency, and PERCLOS70 were investigated as a function of LED color and luminous intensity. The results can be summarized as follows.

(1) The blink duration consistently tended to increase with the increase of luminous intensity for all colors of LED.
(2) The blink frequency tended to increase under the high luminous intensity for both red and white LED which have higher wavelength. As for green LED, the blink frequency was not affected by the luminous intensity. Contrary to the case of red and white LED, the blink frequency of blue LED tended to decrease under the high luminous intensity.
(3) PERCLOS70 of red, white, and green LEDs tended to increase with the increase of luminous intensity. In this manner, the ocular movement characteristics of blue LED could be indicated.

The following issues must be explored in future research.

- The samples of measurements should be increased and the validity of the results should be further verified.
- The finding on the ocular movements is related to the visibility and the detection accuracy of the abnormal food on the belt conveyor system.
- As only young adults were used as a participant, it should be further explored whether a similar result is obtained for other populations such as 40 s, 50 s, and 60 s.

**Acknowledgments** This research was partly conducted under the support fund of local medium and small enterprises by Chugoku Branch, Ministry of Economy, Trade, and Industry.

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# Working with the Elderly—Issues Regarding Registering Their Experience and Knowledge

**Rosângela Míriam Lemos Oliveira Mendonça and Ângela Zampier Lopes Vieira de Oliveira**

**Abstract** The world population is aging and getting to know what they think is then important, not only for affective reasons but also because their needs and opinions, experience and knowledge accumulated during long years, are also of significant weight to our society's productive activities. Nevertheless, many of them have specific communication needs, what makes necessary to study means of efficiently register their experience, knowledge and needs. In this work we describe our experience in developing our project "Food Design and Entrepreneurship" and our strategies of using ergonomic principles, especially during the acquisition of data and information from surveys, to have sound results.

**Keywords** Survey · Elderly · Food design · Entrepreneurship · Cultural identity · Ergonomics · Usability

## 1 Introduction

Working with the elderly is becoming more and more strategic for many reasons. A statistic one is that the population is aging worldwide and Brazil is no exception. The reasons for that are the reduction of the fertility rate that began in the mid-1960s, and the decline in mortality [1]. Therefore a big part of the population is part of this group, which means that the weight of their needs and preferences are high not only for affective reasons but also regarding the power of collectivity.

In a globalized society, what is produced tends to carry multiple information and concept inspirations from various places. "What exists are decentralization, shifting and absence of fixed or solid references for the identities, including those based in

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the idea of nation. This phenomenon consists in a new trend that makes today's humankind seek the past and feel attached to its roots" [2]. Maintaining the cultural identity is essential for the self esteem of a community and also for the value of its production. The richness and attraction of getting to know a place and its people is in experiencing their particular environment, values, habits, way of thinking, abilities, production.

Regarding cultural issues, the elderly are the living record of our traditions. The result of the accumulation of their knowledge and experiences is unique. The deeper the roots of the cultural manifestation the more solid, genuine and valuable it is.

The context of food is especially sensible regarding this feature. The culinary is a manifestation of cultural identity—it reflects a region's production, the community habits and way of life.

> Today, studies about the food and feeding invade Human Sciences from the assumption that the training on food preferences does not occur exclusively for its nutritional aspect, biological. The food is a historical category, since the maintenance and change of patterns of dietary habits and practices have references in their own social dynamics. Food is not just food. Feeding is a nutritional act, eating is a social act, since it is composed by attitudes related to traditions, protocols, behaviors and situations. No food that goes into our mouths is neutral. The historicity of gastronomical sensitivity explains and is explained by cultural and social events as reflection of an era and which has marked an era. In this sense, what you eat is as important as when you eat, where you eat, how you eat and with whom you eat [3].

The breadth of the theme Food and the relationship with other themes is so extense that in France and Italy, for instance, universities of food and its related history were created (Institut des Hautes Etudes du Goût, de la Gastronomie et des des Arts de la Table[1]; Università degli Studi di Scienze Gastronomiche[2]). Food is even a theme of a whole movement—the international Slow Food movement—created in 1986 in Italy and officially founded in Paris in 1989 with the signature of its Manifesto. This movement is a reaction against the Fast Food concept of ready-cooked food for sale, having velocity as main value. The Slow Food instead values the rediscovering of flavors and savors of regional cooking, and the pleasure of following each step of the production of what we eat—from the growing the ingredients in the pace and with controls of nature, going through their harvesting, their distribution, to the preparation of the dish and its savoring.

The gustatory heritage of a society (food, products, recipes), connected to a historical memory, identity, tradition, must be preserved, since it is made up of products that have been widely accepted, which marked an era and are its witness and a way of its recording. This movement also stimulates the education to good taste and strengthens the right to pleasure provided by good food. Besides the cultural aspects, our diet also affects our life standard. Eating well in terms of

[1] http://www.heg-gastronomy.com/en/.

[2] http://www.unisg.it/en/.

quality and quantity is a complex issue that directly affects our health and quality of life.

Considering the influence of food in our society we are developing a project called "Food Design and Entrepreneurship"[3] that has as main purpose to diagnose the cultural profile of a community of the Brazilian region of Minas Gerais regarding the culinary traditions, in order to propose solutions in design for the valorization of local resources and to stimulate entrepreneurship.

To identify the elements of gastronomic heritage it is necessary to research and find answers to questions such as "what products, dishes and recipes could enter the ark of taste to be protected, promoted and valued?"; from what criteria these dishes and products would be chosen? [4]. Among the various possible sources, we highlight here the oral history—interviews with important historical agents. In our research we have identified the elderly, city residents, as guardians of this story.

Therefore, in order to acquire information for the project, besides the bibliographic research and first person observation, we have also interviewed the population. Groups of elderly were our main focus since we needed to rescue traditional resources and habits expressed in recipes and other resources of the culinary context.

Since time and financial resources were limited (as always), and also considering the difficulty of having the availability of the respondents, our approach was to create a survey and apply it in a group of elderly that has regular meetings.

## 2 Acquisition of Preliminary Information

Our research has begun with a bibliographic research, where we got to know the cultural profile of the subject of our investigations.

The community we are working with for the research on "Food Design and Entrepreneurship" is called Rio Acima, in the state of Minas Gerais. Rio Acima is a small town, 39 km from Belo Horizonte, the capital of the state of Minas Gerais. It has started as a settlement around 1736, by pioneers who explored the interior of Minas Gerais in search of gold. Nowadays it has just over 9000 inhabitants, and is known for its beautiful waterfalls. It is the only mining town with 100 % of the territory located within the South APA—Environmental Protection Area which includes 14 municipalities of the Metropolitan Region of Belo Horizonte.

We have also interviewed people that have knowledge about the culture and habits of the population, be for their working for the municipality, be for being a researcher and writer about the culture of Rio.

[3]This project is being developed thanks to the support of FAPEMIG ("Fundação de Amparo à Pesquisa do Estado de Minas Gerais"—Foundation for Research Support of the State of Minas Gerais—Brazil).

## 3 Creating and Planning the Survey

We have prepared our survey considering the good practices and principles that we have developed in previous works [5]. For the success of the application of the survey, ergonomics is a central issue. A well designed survey is essential to its success, both in terms of form and content. Success here means having the desired number of respondents, precise, real answers that can be objectively analyzed to model the reality. It is known that it is difficult to stimulate participants, and that survey response rates are generally low and varies according to the strategy of application and distribution used [6].

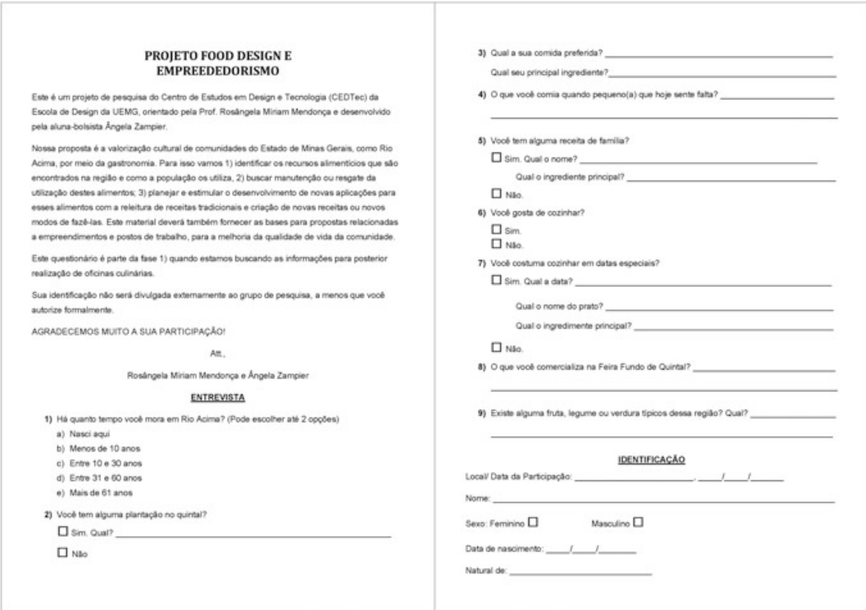
A well prepared survey, with good usability, is a positive factor in the encouragement of respondents in participating in the test and giving valid and reliable[4] answers. Therefore the survey must be easy to understand and easy to answer in its format and content, with clear questions, easy disposition, with answers facilitated and taking as little time as possible. As Iida says, it must be friendly, easy to understand, to perform and as little sensible to errors as possible [8].

We had as goal to keep the questionnaire short and focused, with simple questions, using a vocabulary adequate to the respondents' profile. Since it wouldn't be feasible to list all possible answers, and the study refers mainly to opinions and attitudes, we have used mostly yes/no questions with comment field in order to try and make answers shorter and more objective. In terms of its organization, the survey had an introduction where our research group was presented, the objective of the research explained and where we thanked the respondents' participation. The survey was composed by 9 questions and an identification section: the initial questions addressed general, easy to answer issues to engage the respondent; the middle ones contained the primary, most important questions; and the closing section asked demographic information (Fig. 1).

We have also considered the special needs of our elderly respondents, taking into account their senescent characteristics (such as decrease in length and elasticity of the musculoskeletal system; decreasing of the number of neurons, of the nerve conduction velocity, of the reflexes intensity, and restrictions of motor responses). Therefore we have used text written with bigger (but not enormous) fonts, considering the decline in visual acuity.

We have also planned assisted surveys, due to the importance of personal relationship to the quality of answer. We have privileged working with groups, reading questions and answers aloud also for the benefit of having a higher sample, and counting on volunteers to help closely those who would seem to have difficulties or doubts. Therefore, as strategy of application, we have prepared a group of monitors to help in the application of the questionnaire. They have participated also

[4]Validity derives from the latin validus which means the capacity of measuring the "real", or the capacity of an instrument to avoid error. Reliability is defined as the capacity of an instrument of not changing its results, being used by diverse researchers or in distinct moments [7].



**PROJETO FOOD DESIGN E EMPREEDEDORISMO**

Este é um projeto de pesquisa do Centro de Estudos em Design e Tecnologia (CEDTec) da Escola de Design da UEMG, orientado pela Prof. Rosângela Miriam Mendonça e desenvolvido pela aluna-bolsista Ângela Zampier.

Nossa proposta é a valorização cultural de comunidades do Estado de Minas Gerais, como Rio Acima, por meio da gastronomia. Para isso vamos 1) identificar os recursos alimenticios que são encontrados na região e como a população os utiliza, 2) buscar manutenção ou resgate da utilização destes alimentos; 3) planejar e estimular o desenvolvimento de novas aplicações para esses alimentos com a releitura de receitas tradicionais e criação de novas receitas ou novos modos de fazê-las. Este material deverá também fornecer as bases para propostas relacionadas a empreendimentos e postos de trabalho, para a melhoria da qualidade de vida da comunidade.

Este questionário é parte da fase 1) quando estamos buscando as informações para posterior realização de oficinas culinárias.

Sua identificação não será divulgada externamente ao grupo de pesquisa, a menos que você autorize formalmente.

AGRADECEMOS MUITO A SUA PARTICIPAÇÃO!

Att.,

Rosângela Miriam Mendonça e Ângela Zampier

**ENTREVISTA**

1) Há quanto tempo você mora em Rio Acima? (Pode escolher até 2 opções)
   a) Nasci aqui
   b) Menos de 10 anos
   c) Entre 10 e 30 anos
   d) Entre 31 e 60 anos
   e) Mais de 61 anos
2) Você tem alguma plantação no quintal?
   ☐ Sim. Qual? ____
   ☐ Não
3) Qual a sua comida preferida? ____
   Qual seu principal ingrediente? ____
4) O que você comia quando pequeno(a) que hoje sente falta? ____
5) Você tem alguma receita de família?
   ☐ Sim. Qual o nome? ____
   Qual o ingrediente principal? ____
   ☐ Não.
6) Você gosta de cozinhar?
   ☐ Sim.
   ☐ Não.
7) Você costuma cozinhar em datas especiais?
   ☐ Sim. Qual a data? ____
   Qual o nome do prato? ____
   Qual o ingredimente principal? ____
   ☐ Não.
8) O que você comercializa na Feira Fundo de Quintal? ____
9) Existe alguma fruta, legume ou verdura tipicos dessa região? Qual? ____

**IDENTIFICAÇÃO**

Local/ Data da Participação: ____, ___/___/____

Nome: ____

Sexo: Feminino ☐ Masculino ☐

Data de nascimento: ___/___/____

Natural de: ____

**Fig. 1** The survey applied

in the creation of the questionnaire so that they would understand the reasons for the procedures and be prepared to react to different situations during the effective implementation of the survey. This would be especially important since illiteracy is frequently an issue (which we had experienced in a previous research) and also as a strategy considering time limitations.

## 4 The Mobilization of the Group to Be Interviewed

By interviewing a group of people that take part of local administration (from the Department of Sports and Leisure) and a historic researcher from the community (D. Eunice Silva Santos), we have decided to apply our survey in a group of elderly called “Comunidade Kolping Santo Antônio de Rio Acima” (Kolping Community). This is a social group formed by of 60–80 elderly, who have regular meetings and perform a diversity of leisure and memory enhancing activities.

We were given the contact of the coordinators of this group. We made telephonic contact with them, where our community hosts have first presented us. Then we have explained our project, needs and goals, and finally we set an appointment with the Kolping community.

## 5 Implementing the Survey

We have agreed with the coordinators of the group that they would allow us to conduct the meeting and use their time for the activities of our survey. They are normally 2-hour meetings which end with a communitarian snack.

A group of students and researchers of our university came to the meeting prepared to perform the survey. We have also invited to participate from our activities, leaders from the community, known by group, in order to have they informed of our project and activities with the community and also to transmit to our respondents security and reliability.

Although we expected some level of illiteracy, we were surprised when told that the vast majority of the group was in this condition. Therefore it was essential our strategy of assisted survey, having monitors to read and explain the questions and filling in the answers on the questionnaire.

We have begun by presenting ourselves and our research. We explained the concept of Food Design, the goal of our survey, presented previous works of our group in the area of Food Design, how we intended to work, and the results we were expecting with that work.

After presentation, we divided the group into 8 smaller groups, each one with one monitor. The dynamics of filling in the questionnaire consisted in: distributing the questionnaire to each respondent; the monitor of each group reading aloud each question for the group; the monitor taking the questionnaire from each respondent, filling it in and giving it back. Whenever necessary, when a respondent had doubt about the question the monitor would read and explain it again. Nevertheless they were careful not to induce answers, as adverted by Nogueira, by making the respondents choose an option based on what the researcher stresses more, instead of their own opinion [9, 10] (Fig. 2).

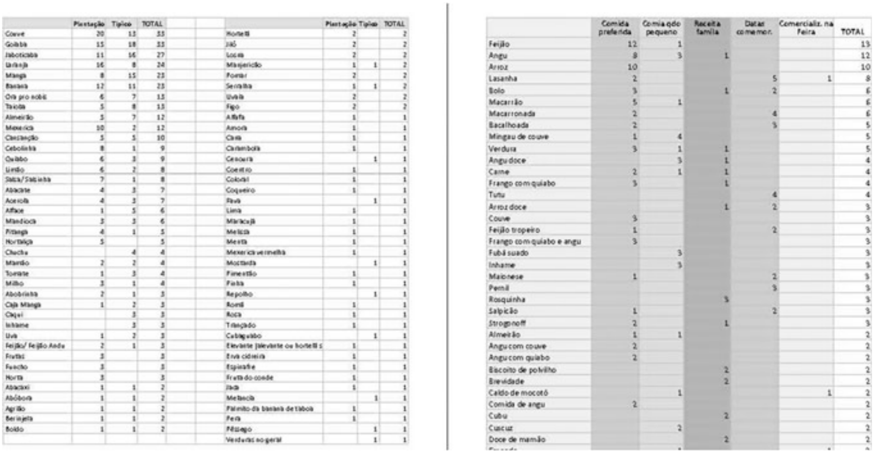
This process was a bit time consuming, since each question had to be read and explained more than once. Nevertheless, since they were small groups of around 7 people, it was not tiring and we managed to keep schedule.

In the end we have all commemorated, making a prayer of thanks, eating together and taking photographs.

## 6 Compilation of Results

We have compiled the results grouping the answers into categories. First we have tabulated the answers within the categories: participant, what it is planted in the backyard, preferred food, what he used to eat as a kid, family recipe and typical regional food. Then we have organized in two groupings: ingredients and dishes. We have counted the occurrences of each answer and ranked the two lists. With this work, we had indications of what was available in the region, some traditional ingredients and dishes (Fig. 3).

**Fig. 2** Presentation of the "Food Design and Entrepreneurship" project to the Kolping Community (*top left*); one of the monitors performing the interview and filling the questionnaire with the participant's answer (*top right*); praying time, before the afternoon's snack (*bottom left*); "Comunidade Kolping Santo Antônio de Rio Acima" and the "Food Design and Entrepreneurship" groups, at the end of the meeting (*bottom right*). Team's file, 2015



| | Plantação | Típico | TOTAL |
|---|---|---|---|
| Couve | 20 | 13 | 33 |
| Goiaba | 15 | 18 | 33 |
| Jabuticaba | 11 | 16 | 27 |
| Laranja | 16 | 8 | 24 |
| Manga | 8 | 15 | 23 |
| Banana | 12 | 11 | 23 |
| Ora pro nobis | 6 | 7 | 13 |
| Taioba | 5 | 8 | 13 |
| Almeirão | 5 | 7 | 12 |
| Mexerica | 10 | 2 | 12 |
| Cansanção | 5 | 5 | 10 |
| Cebolinha | 8 | 1 | 9 |
| Quiabo | 6 | 3 | 9 |
| Limão | 6 | 2 | 8 |
| Salsa/Salsinha | 7 | 1 | 8 |
| Abacate | 4 | 3 | 7 |
| Acerola | 4 | 3 | 7 |
| Alface | 1 | 5 | 6 |
| Mandioca | 3 | 3 | 6 |
| Pitanga | 4 | 1 | 5 |
| Hortaliça | 5 | | 5 |
| Chuchu | | 4 | 4 |
| Mamão | 2 | 2 | 4 |
| Tomate | 1 | 3 | 4 |
| Milho | 3 | 1 | 4 |
| Abobrinha | 2 | 1 | 3 |
| Cajá Manga | 1 | 2 | 3 |
| Caqui | | 3 | 3 |
| Inhame | | 3 | 3 |
| Uva | 1 | 2 | 3 |
| Feijão/ Feijão Andu | 2 | 1 | 3 |
| Frutas | 3 | | 3 |
| Funcho | 3 | | 3 |
| Horta | 3 | | 3 |
| Abacaxi | 1 | 1 | 2 |
| Abóbora | 1 | 1 | 2 |
| Agrião | 1 | 1 | 2 |
| Berinjela | 1 | 1 | 2 |
| Boldo | 1 | 1 | 2 |

| | Plantação | Típico | TOTAL |
|---|---|---|---|
| Hortelã | 2 | | 2 |
| Jiló | 2 | | 2 |
| Losna | 2 | | 2 |
| Manjericão | 1 | 1 | 2 |
| Pomar | 2 | | 2 |
| Serralha | 1 | 1 | 2 |
| Uvaia | 2 | | 2 |
| Figo | 2 | | 2 |
| Alfafa | 1 | | 1 |
| Amora | 1 | | 1 |
| Cana | 1 | | 1 |
| Carambola | 1 | | 1 |
| Cenoura | | 1 | 1 |
| Coentro | 1 | | 1 |
| Colorau | 1 | | 1 |
| Coqueiro | 1 | | 1 |
| Fava | | 1 | 1 |
| Lima | 1 | | 1 |
| Maracujá | 1 | | 1 |
| Melissa | 1 | | 1 |
| Menta | 1 | | 1 |
| Mexerica vermelha | 1 | | 1 |
| Mostarda | | 1 | 1 |
| Pimentão | 1 | | 1 |
| Pinha | 1 | | 1 |
| Repolho | | 1 | 1 |
| Romã | 1 | | 1 |
| Roça | 1 | | 1 |
| Trançado | 1 | | 1 |
| [illegible] | | 1 | 1 |
| Elevante (elevante ou hortelã s | 1 | | 1 |
| Erva cidreira | 1 | | 1 |
| Espinafre | 1 | | 1 |
| Fruta do conde | 1 | | 1 |
| Jaca | 1 | | 1 |
| Melancia | | 1 | 1 |
| Palmito da banana de taboa | 1 | | 1 |
| Pera | 1 | | 1 |
| Pêssego | | 1 | 1 |
| Verduras no geral | | 1 | 1 |

| | Comida preferida | Comia qdo pequeno | Receita família | Datas comemor. | Comercializ. na Feira | TOTAL |
|---|---|---|---|---|---|---|
| Feijão | 12 | 1 | | | | 13 |
| Angu | 8 | 3 | 1 | | | 12 |
| Arroz | 10 | | | | | 10 |
| Lasanha | 2 | | | 5 | 1 | 8 |
| Bolo | 3 | | 1 | 2 | | 6 |
| Macarrão | 5 | 1 | | | | 6 |
| Macarronada | 2 | | | 4 | | 6 |
| Bacalhoada | 2 | | | 3 | | 5 |
| Mingau de couve | 1 | 4 | | | | 5 |
| Verdura | 3 | 1 | 1 | | | 5 |
| Angu doce | | 3 | 1 | | | 4 |
| Carne | 2 | 1 | 1 | | | 4 |
| Frango com quiabo | 3 | | 1 | | | 4 |
| Tutu | | | | 4 | | 4 |
| Arroz doce | | | 1 | 2 | | 3 |
| Couve | 3 | | | | | 3 |
| Feijão tropeiro | 1 | | | 2 | | 3 |
| Frango com quiabo e angu | 3 | | | | | 3 |
| Fubá suado | | 3 | | | | 3 |
| Inhame | | 3 | | | | 3 |
| Maionese | 1 | | | 2 | | 3 |
| Pernil | | | | 3 | | 3 |
| Rosquinha | | | 3 | | | 3 |
| Salpicão | 1 | | | 2 | | 3 |
| Strogonoff | 2 | | 1 | | | 3 |
| Almeirão | 1 | 1 | | | | 2 |
| Angu com couve | 2 | | | | | 2 |
| Angu com quiabo | 2 | | | | | 2 |
| Biscoito de polvilho | | | 2 | | | 2 |
| Brevidade | | | 2 | | | 2 |
| Caldo de mocotó | | 1 | | | 1 | 2 |
| Comida de angu | 2 | | | | | 2 |
| Cubu | | | 2 | | | 2 |
| Cuscuz | | 2 | | | | 2 |
| Doce de mamão | | | 2 | | | 2 |

**Fig. 3** Part of the tables of the compiled information: the ingredients (on the *left*) and dishes (on the *right*)

The results were taken to be validated in a meeting with a Local Committee formed by representatives of “Rio Acima”, chosen from their knowledge about the local culture as residents, researchers and staff from local administration. We have organized and ranked the information in a table so that the results could converge.

This information gave us material to plan a workshop with professionals working in the food context, creating dishes that would mean an easy and interesting way of using them, stimulating a intuitive balanced meal using carbohydrates (breads, pasta, rice, potatoes and cereals, which is source of energy); colored vegetables (supplying iron, fiber, minerals and vitamins), fruits (which are source of vitamins); meat, eggs and grains (supplying large amount of protein which helps the strengthening of bone structure, tissue formation of the brain, the muscles of various organs and skin, being beneficial to healing any wounds), milk and dairy products (with minerals and proteins which help in the formation of muscle, bone and nerve tissues), lipids (oils and fats) and sugars (that supply lots of energy but, since it is stored as adipose tissue, nutritionists recommend moderate consumption).

We have tried also to give priority to seasonal produce and think about some dietary restrictions.

We are now processing the information and recording the process and results in reports, especially about the final workshop. We are going to publicize the results, aiming at thanking and providing a return to the participants, contributing to the community for the improvement of their food quality and nutrition, and also of business opportunities.

Also in this phase, the ergonomics will be an issue. We are planning to use means that are largely accessible for all. Social media will be a chosen option since it is costless and because a large portion of the society has access to it. Nevertheless some of the simpler and older people may have difficulty in accessing this information. Therefore we are planning to again count on the coordinators of the Kolping Community to define activities that would transmit gradually the results of our research. We are concerned with usability and illiteracy, so we intend to produce visual recipes.

## 7 Conclusions

We are working with a theme that has the power of changing the quality of life of a community. For this goal, we are counting on the knowledge of the elderly, and to get information from them it is necessary to work carefully with the means of communication. Ergonomics and usability principles were resources that we used to improve the efficiency of our work.

During our interaction with the elderly to apply the survey, it could be noticed that many of the participants felt comfortable with our questionnaire/interview format. Talking to the participants of the survey rather than just handing them an empty form to fill in, humanized the process and made them more confident to tell their story, their preferences and memories, which was exactly what the team intended to achieve. Besides, choosing a period of their day that was already dedicated to have social interactions, in group activities, has also contributed for the good will in participating.

Our approach then, proved to be an efficient method of surveying, especially considering the peculiarities of working with the elderly. We hope that this result may contribute for small changes in the community and to be able to keep working in this theme, counting on the aid of ergonomics.

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# Ergonomic/Human Factors in the Design Process. Methodological Tool for Characterization of the User

**Gustavo Sevilla and Luz M. Sáenz**

**Abstract** This paper presents a classroom teaching experience from Ergonomics and Design 2 at Industrial Design Faculty in the Universidad Pontificia Bolivariana (UPB) involving the development and application of an instrument. This exercise allows the students to explain the key component of the ergonomic system to the user(s), increase the designer's knowledge of the user(s) and identify human factors and needs that can be met by the product's functions. The user characterization workshop constitutes a tool for the implementation of ergonomic criteria in the design process.

**Keywords** Teaching-learning process · Ergonomics and design · Workshop for analysis · The user

## 1 Introduction

The Industrial Design Faculty at UPB deems it important that the design process develops alongside and correlatively to ergonomic principles, and that the chosen method provides a logical framework of procedures [1] that integrates both disciplines and organizes the process so factors relevant to the project are not excluded.

Likewise, when the common elements of Ergonomics and Design are integrated, the result/product should incorporate the characteristics, capacities and limitations of the user, the requirements of the product and the conditions of the context—both environmental and social—in which it will be used [2].

This idea has become a support tool for teaching and research, and has been proposed as the conceptual and methodological basis of the Ergonomics Research

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Division of UPB's Design Studies Group [3] and of the Design Process. This is in line with the Design Faculty's Disciplinary Model, which forms the basis for the education of industrial designers [4].

The framework of this proposal, which connects both disciplines, includes an activity developed in the classroom (the teaching-learning process of Ergonomics in the Design Process) that applies data-collection tools that help understand in detail the different components in the ergonomic system; contribute to data systematization; and facilitate design requirements. This article features a data-collection tool that can be used to characterize the user or groups of users.

## 2 Ergonomic—Design Integration: A Methodological Understanding

According to the Ergonomics Division of UPB's Design Studies Research Group, important thematic units, subjects, elements and components should be analyzed during the design product's configuration process using the User-Product-Context System. Moments/activities should also be developed that allow future designers to expand the process in a way that is systematic and coherent to Ergonomics.

The system's thematic units refer to key subjects, elements or components that should be analyzed during the design product's configuration process, and represent the fundamental reason for ergonomic intervention. The units are the starting point for this alternative methodology: the user, the product and the context whose elements are similar to the Man-Machine-Environment system i.e. the same components but from the perspective of the activity: the person who uses products (resulting from the design process) in particular contexts.

The User: includes a description of the user or group of users through physical, cognitive, demographic, geographic, behavioral and intrinsic (unique or important to a particular group) variables.

The Product: the recognition and evaluation of physical attributes/properties; functional-operational, esthetic-communicative and technical-productive characteristics; design references; the requirements that define form; the conditions that influence the design; historical development; cultural impact; and others.

The Context: allows characterization of environmental factors (space, light, noise, temperature, etc.); urban-architectural elements where the activity or product use is developed; and cultural factors that influence who we are and what we do.

The actions carried out by the user and the relationships that are established between the variables in the ergonomic system constitute the Activity i.e. the joint activities and tasks that are carried out to achieve a specific target or objective. The analysis of the activity involves the study of processes and/or tasks, times, implementation methods, techniques, human resources, materials and technical aspects.

The moments and activities of this methodological proposal constitute a sequence that explains the situation from the human component, the objects/machines that use the methodology and the environment in which they are used. The possibility exists of support and intervention of different disciplines for a more comprehensive approach i.e. from the anthropocentric, systemic and inter-disciplinary perspective of ergonomics.

The first moment focuses on an INFORMATION gathering stage or activity (a result of studying and interpreting the user's characteristics and requirements, as well as the dynamics of context that help to define a design problem/opportunity [5] see Fig. 1).

The next stage is idea development—or the Creation stage. During this stage, the product's formal and material properties are configured and different design alternatives are presented that should include as many of the requirements obtained in the first stage as possible. The development of ideas—or Integration—is incorporated into a moment of FORMALIZATION. This comprises the translation of the verbal concept into a formal proposal, and which represents a solution to the previously identified problem/opportunity through the creation of an object [5]. It should be noted that at this stage, the proposal is a representation and not an object that has been produced.

A moment of CONFORMATION then sees the form—be it a product or a service—introduced to the context. A materialization process generates a series of values that are added to the product and that give it meaning (be it commercial, institutional or cultural). This allows individuals to recognize in this final form a

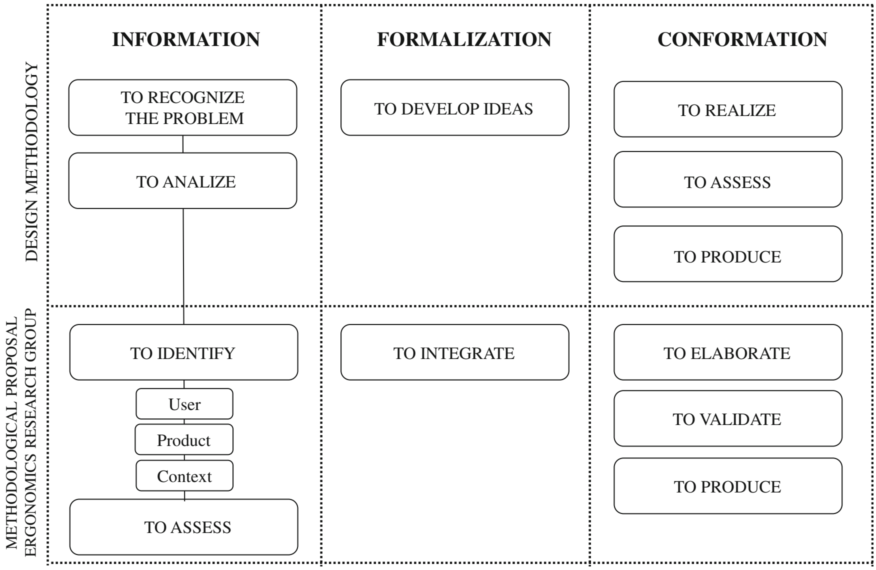



**Fig. 1** The design process and ergonomics intervention, parallel and complementary activities

solution to the original problem (which society may or may not have recognized) that acquires a practical sense once it has been implemented. During this stage, a three-dimensional representation of one or more design alternatives should be developed.

From an ergonomic intervention perspective, the Conformation stage also includes a validation of the use relationship and a verification of results for the product's definitive implementation.

## 3 Ergonomic—Design Integration: A Methodological Understanding

The general guidelines of UPB's teaching model focuses on learning; the students' active participation in knowledge building; the professor's role as mediator; research; experimental work; and the practice of duly accompanied independent activities [4].

Thus, a relationship between Ergonomics/Human Factors and the Design process is methodologically established in the Industrial Design Faculty's Ergonomics and Design courses. This can be demonstrated in every step of the process; the relevant criteria for each discipline; and how these should be developed in a parallel and complementary way from the beginning of the configuration process of the objects/products. From an educational perspective, strategies are conceived for the development of skills related to the understanding of the characteristics, needs and requirements of the users—a fundamental component in the design process.

A series of workshops have been designed for the analysis and integration of the USER, PRODUCT, CONTEXT and ACTIVITY variables in the design process's first stage (INFORMATION). These workshops help the student to characterize these variables, identify and classify information, establish relationships for the design project and define the requirements for the product according to Ergonomics/Human Factors.

The workshops include quantitative and qualitative variables and indicators that should be observed and analyzed by the student. This permits a systemization of data, classification and analysis.

The term "characterization", in a design context, refers to the identification of the qualities and distinguishing features of the group of users who will use the product, the objects involved in the activity, the use context and the activity itself. In that sense, the workshops are a support tool to analyze the variables that should be considered from an Ergonomics perspective in the design process of new products and the re-design of existing products.

For the creation of workshops and the characterization of the U—P—C—A system (variables of the ergonomics system), the required information has been classified by factors. A factor is that element that helps to define a variable's characteristics, which in this case refers to human factors. This is intended as a support tool for the INFORMATION stage in the design process.

## 4 The User(s) Profile Workshop

The objective of the workshop is to determine the qualities or typical features of the user or group of users through physical, cognitive, demographic, geographic, behavioral and intrinsic (unique or important to a particular group) indicators. The profiling exercise allows user groups and objectives to be identified.

**Identifying product users**
In this first stage, the user is identified according to their level of interaction with the product(s). See Table 1.

**The role of the user and intervention level**
The following describes the role of each type of user and their relationship with the product. This determines if the characteristics/needs of the user should be considered during the object configuration stage, and the degree of user interaction. See Table 2.

**Defining the specific characteristics about activities of the user(s)**
Table 3. Includes information about activities realized by the user(s): what, where, how realize the activity/use or product.

The anatomical factor refers to a detailed description of the form, surface characteristics and physical description of the user(s).

The anthropometric factor identifies reference dimension tables that correspond to the user's sex and age range. The objective of the biomechanical factor is to

**Table 1** User categories

| 1. Product users | |
|---|---|
| User type | User name<br>(Named, identified or distinguished with a particular title) |
| Who is/are the primary or direct user(s) of the product? | |
| Who is/are the secondary user(s) of the product? | |
| Who is/are the collateral user(s) of the product? | |

Note: *Primary user(s)* Those that use the product on a frequent basis
*Secondary user(s)* Those that use the product on an occasional basis
*Collateral user(s)* Those that influence or are affected by the product, but do not interact with its functions. The latter two groups can also be referred to as "indirect users" [6]

**Table 2** Categories an role of the Users

| 2 User type | | | |
|---|---|---|---|
| Categories | Role | Should be considered for the design? | |
| | | Yes | No |
| Primary user(s) | Space for a description of the user's role in the U-P-C-A system. | | |
| Secondary user(s) | | | |
| Collateral user(s) | | | |

**Table 3** About activities and or use

| 3. Activities of the user | |
|---|---|
| 3.1. General information | |
| 3.1.1. User name: (User name according to Table 1) | 3.1.2. User type:<br>Primary Secondary Collateral |
| 3.1.3. Activity where the object's use is defined | 3.1.4. User occupation |
| 3.1.5. Motive for use (Why does the user use the product?) | 3.1.6. Frequency of use<br>Minutes Hours Months Years<br>Range of use |
| 3.1.7. Where the activity/use of the product is carried out | 3.1.8. Objects that intervene in the activity<br>(List of objects and a description of their function during the activity) |

define criteria related to posture and the driving variables associated with use/activity during the analysis process. See Table 5.

The cognitive factor refers to a description of the user's abilities, limitations and mental processes in relation to use/activity. See Table 6.

The sociocultural factor refers to a description of those characteristics linked to living and working conditions, income, educational background and the community to which the user(s) belong.

Tables 3, 4, 5, 6, 7 should be completed for each one of the users who participates in the situation under analysis.

**Defining product requirements according to the characterization of the user(s)**
The information obtained helps to define general requirements, and expressed in formal, material and functional attributes in relation to each one of the criterion developed in the workshop (Table 8).

**Table 4** About activities and or use

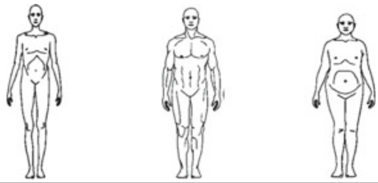
| 4. Anatomical factor | |
|---|---|
| 4.1. Sex | ____Masculine ____ Femenine ____N/A |
| 4.2. Sexual orientation | ____Heterosexual_____Lesbian/Gay____Bisexual ____Transgender ____Intersexual _____N/A |
| 4.3. Age bracket | ____Infant ____Young person ____Adult Senior citizen ____Age range |
| 4.4. Physical type | Ectomorph Mesomorph Endomorph N/A  |
| 4.5. Functional limitations (physical—cognitive) | ____Yes ____No What? |

**Table 5** Anthropometric and Biomechanical criteria

| 5. Anthropometric and biomechanical factor | |
|---|---|
| 5.1. Tables anthropometrics Age range (Are there anthropometric tables for the user?) | ____Yes ____No Include references |
| 5.2. Biomechanical factor | |
| 5.3. Posture | ____Biped ____ Seated ___Lying ____Face up ____ Others |
| 5.4. Driving variables (Special movements—strength—resistance—speed—flexibility—balance) | ____Yes ___No What? |

**Table 6** Cognitive criteria

| 6. Cognitive factor | |
|---|---|
| 6.1. Special cognitive skills (Perception—attention—memory—reasoning—executive duties—specific language—spatial/temporal orientation—apraxia) | ____Yes ____No What? |
| 6.2. Preparatory training (Does the user require preparatory training to carry out the activity/use the object?) | ____Yes ____No What? |

**Table 7** Sociacultural criteria

| 7. Sociocultural factor | |
|---|---|
| 7.1. Social stratification | ____Indigent ____Lower<br>____Lower-middle ____Middle<br>____Upper-middle ____Upper |
| 7.2. Education level<br>(Does the user require a level of education to carry out the activity/use the object?) | ____Primary ____Secondary<br>____University<br>____Postgraduate<br>____Technical<br>____Course/Training<br>____Self-taught ____N/A |
| 7.3. Salary (COP) | ____Unwaged<br>____Below minimum wage<br>____Minimum wage<br>____Between minimum wage and $1'.000.001<br>____Between $1'.000.001 and $2'.000.000<br>____Between $2'.000.001 and $4'.000.000<br>____Between $4'000.001 and $8'000.000<br>____Between $8'000.001 and $10'000.000<br>____More than $10'000.000 |
| 7.4. Esthetic values<br>(In the user/activity/object design) | Perception criteria |
| 7.5. Language | |
| 7.6.Geographical location of the user(s) | |
| 7.7. Demographics<br>(Statistically how many people carry out the activity/use the object) | ____% Locally ____% Nationwide<br>____% Worldwide |

**Table 8** Product requirements

| 8. Table of product requirements | | | | | | |
|---|---|---|---|---|---|---|
| # | General requirement | Mandatory | Desirable | Qualitative | Quantitative | Specific requirement Characteristic expressed as a numerical value or specific quality |

## 5 Conclusions

The application of this tool allows the students to:

- Increase the designer's knowledge of the users.
- Obtain information to improve the interface between the object and the user(s).
- Identify the user's actual needs, and if they can be met by the product functions.
- Align the product requirements with the user group's features.
- Implement ergonomic criteria to optimize the user's relationship of use, security and confidence with the product.
- Obtain criteria to redesign existing products and encourage the design of new products.
- Plan and implement strategies geared to improving the User-Product-Context relationship.

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# Improving Medication Adherence for the Elderly in China-An User Study in Design

**Qian Zhou, Long Liu, Qianwen Zheng and Jinhua Li**

**Abstract** This study aims to (1) understand elder patient's current attitude, knowledge and behavior of medication adherence, (2) trying to find out the detail reasons of adherence and non-adherence, and opportunities in design perspective. Methods. Questionnaire and interview are two main methods applied to achieve the goals. Two key findings are that patient's subjective attitude determine their behavior, and care provider play an essential role to influence adherence. Therefore, educating and motivating the patient, spreading of the care provider are the two concluded design strategies for improving medication adherence. There is a need to consider the medication adherence as a dynamic, systematic process according to both medication adherence related factors and patient lifestyle.

**Keywords** Medication adherence · Chinese elderly · Behavior change

## 1 Introduction

As people growing older, physical or mental capabilities, self-care ability and health condition will decrease somehow, which makes the elderly more vulnerably suffer from chronic disease or diseases that need long-term treatment. In China, with the increase of elderly population, the healthcare for them is becoming a widely concern issue. Although medication is an effective approach to the majority of treatments all over the world, statistics show that average only 50 % patients are adherent to prescriptions in developed countries [1, 2]. In China, this number is around 40 % (43 % according to [3], 41.1 % according to [4]. 41.3 % according to [5]). It is clear that following medical prescriptions is a global challenge, which would have a greater impact on reducing healthcare cost and enhancing health system effectiveness and patient's safety [6].

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The definition of adherence refers to the extent to which patients' behavior would correspond with the agreed recommendations given by health care provider on taking medication, following a diet and implementing life changes [7, 8]. This concept has been developing from another term-compliance, which describes the extent to which patients' behavior would match the provider's recommendations [9]. Comparing to compliance, adherence emphasise more on the patient's role in decision-making and patient's freedom of whether to follow the medical recommendation or not [10]. In China, there has not been developed a consistently agreed Chinese term to describe the idea of the medication adherence. The descriptions are slightly different according to authors' own understanding and interpretation, and they vary from different discipline's concerns as well. In addition, few Chinese adherence descriptions include the idea of emphasis patients' willingness.

The World Health Organization (WHO) have defined the factors that determined adherence with five interplayed dimensions, which are (1) social/economic factors; (2) provider-patient/health care system factors; (3) condition-related factors; (4) therapy-related factors and (5) patient-related factors [6]. Especially for the elderly, both physiological and psychological factors strongly influence the adherence level. From a physiological standpoint, the elder patient are more vulnerable to hearing loss, impaired vision, memory deterioration, cognitive decline, distraction, emotional instability, less control of self-emotion and so forth. However, from the psychological view, the old patients may more easily feel anxiety, intense fear, depression when they facing the diseases. In China, there have been several studies aiming to explore the reasons for non-adherence and adherence. For the elder patients, according to literatures in China from 1994 to 2007, the reasons for non-adherence include memory problem with lower cognition ability, finance state, increase in drug dosage and frequency, adverse drug effects, longer drug using duration, slow drug efficacy, health care resource and condition, lack in sufficient guidance, patient's personality or characteristic and education level [11]. In recent study, there are some other non-adherence reasons such as forgetting, being symptoms-free for a period, less available with caregiver professional guidance and less family or social support [12, 13].

In China, the existing medication adherence studies are mainly in the medical science, pharmacy, nursing and rehabilitation field. Meanwhile, healthcare design is becoming more and more important to cope with some issues like adherence with some solutions developed to support patient's medication taking, such as electric reminder, pillbox, etc. However, there is insufficient user-centred research to support the patient-support design solution. Therefore, the goals of this study are to:

(1) Understand Chinese elder patient's current attitude, knowledge and behavior of medication adherence
(2) Find out the reasons of adherence and non-adherence; insights and opportunities for improving the medication adherence in design perspective.

# 2 Methods

The study was conducted in two phases: questionnaire and interview. The questionnaire study mainly aimed to understand the elder patients' generally attitude towards medication adherence, collecting the elder people's living-related data and adherence related data with five-dimension adherence influenced factors. Moreover, it was the screening tool for the next interview candidates.

The interview phrase was conducted with both elder patients selected from the questionnaire study to dig deep reasons behind the adherence or non-adherence and collecting data of the elderly's lifestyle and living routine. In addition, the interview of care providers is to understand their current knowledge and attitude towards medication adherence issue, to collect their job-related data resource and future expectation of the health care domain.

## *2.1 First Phase*

The questionnaire was designed with four parts: medication adherence, disease and therapy, health care and physician-patient relations, living condition and lifestyle. In each part, questions began with the objective ones for waking their recollection and ended with subjective ones for collecting personal opinion and attitude.

**Medication adherence**. A self-report questionnaire, the eight-item Morisky Medication Adherence Scale (MMAS-8) was used to measure medication adherence. All items were translated into Chinese from the original scale [14]. Other questions related to the knowledge and attitude to the medication adherence were set after the scale.

**Disease and therapy**. Questions in this part aimed to collect information on participant's disease categories and treatments; other questions were medication-taking dosage, frequency, and patients' attitude to the overall therapy recommendation.

**Health care and physician-patient relations**. Questions aimed to collect information on the patients' hospital visiting habit and normal behavior in the health care process. In addition, detail questions related to the content of the medical recommendation given by physician, patients' satisfaction or opinion towards the recommendation, self-reported physician-patient relations were included.

**Living situation and health related lifestyle**. Detail information on elder patient including demographic information, family living condition, economic state, means and channels of health-related information acquisition, health diet and physical exercise situation (Table 1).

Participants were recruited from Shanghai (tier-1), Hangzhou (tier-2), Zhuji (tier-3), three cities in China. To achieve the study goals, participants were chose with following standards:

**Table 1** Demographic and basic information (n = 60)

| Characteristic | Number |
|---|---|
| Gender | |
| Male | 25 (42.0 %) |
| Female | 35 (58.0 %) |
| Age (mean) | 61.0 |
| Living condition | |
| Living lone | 10 (17.0 %) |
| Live with family | 50 (83.0 %) |
| Times of medication taking per day | |
| Once | 18 (30.0 %) |
| Twice | 16 (26.7 %) |
| Three times | 26 (43.3 %) |
| Numbers of medication taking per time | |
| 1–2 | 34 (56.7 %) |
| 3–4 | 21 (35.0 %) |
| 5–6 | 5 (8.3 %) |
| Frequency of physical exercise | |
| Rarely/never | 16 (26.7 %) |
| Once in awhile | 12 (20.0 %) |
| Sometimes | 13 (21.7 %) |
| Always | 15 (25.0 %) |
| Almost everyday | 4 (6.7 %) |
| Way of communication | |
| Telephone calls | 5 (8.3 %) |
| Cellphone calls and SNS | 26 (43.3 %) |
| Smart phone app | 29 (48.3 %) |

- Over 50 years old
- Outpatient
- At least one year medication-taking experience
- At least once per day of medication-taking
- At least having one chronic disease
- Having hospital experience within 6 months.

## 2.2 Second Phase

The interview study was conducted as a semi-structural interview after the questionnaire study being done. The previous questionnaire was utilized as the guidance and fundamental material for the interview including same four topics as displayed in the questionnaire study. All the interview participants were chosen from the questionnaire study. The way and sequence of asking questions was flexible

**Table 2** Basic information on elder patient interviewees

| No. | Age | Gender | Living situation | Medication adherence level |
|---|---|---|---|---|
| 1 | 58 | Female | Retied | High |
| 2 | 83 | Male | Retied | Low |
| 3 | 55 | Male | Employee | Low |
| 4 | 69 | Female | Retied | Medium |
| 5 | 79 | Male | Retied | Medium |

**Table 3** Basic information of care provider interviewees

| No. | Age | Gender | Job |
|---|---|---|---|
| 1 | 52 | Male | Specialist |
| 2 | 48 | Male | Doctor |
| 3 | 45 | Female | Pharmacist |
| 4 | 35 | Female | Nurse |
| 5 | 32 | Female | Nurse |

according to each participant. However, all the questions were set for the same following objects:

- Dig deep of the current answers showed from the questionnaire
- Understand more of the participant's lifestyle and living environment
- Find out the reasons of being low adherence and high adherence (Table 2).

As known from the literature, physician play an important role in the medication treatment. For understanding the care providers in the system, it was planned to collect following information:

- Brief introduction of the job content and workload
- The whole process of treating a patient
- Experience of the elder patient with chronic disease
- Experience of the medication adherence issue
- Attitude and standpoint towards physician-patient relations
- Expectation of the future health care domain (Table 3).

# 3 Results

## *3.1 Medication Adherence*

In general, the medication adherence level is low in China. In total 60 participants, it was shown that 46 of them were measured into the low medication adherence category (77 %). Almost none of the participants have heard about the idea of medication adherence before. However, part of them have the knowledge related to it in somehow.

The subjective will of taking medication is low. From the data of the MMAS-8, it is illustrated that 71.7 % participants agreed that taking medicine every day is an inconvenience job, and feeling hassled and tried of sticking to the treatment recommendation. Answers from the interview study shown the same result. All the interviewee regarded the medication taking as a job that patient have to do for maintain health, but not a job they would feel happy and positive of doing it.

It is the common case that people reduce or stop taking mediation without telling doctor. As Fig. 1 showed, 41.7 % people have ever done it because of adverse drug effect; other 68.3 % had this experience since they felt the symptoms are under control. In the interview study, two of five interviewee reported that they believe an old saying in China that "As long as it is a medicine, it has to have some poison components." Therefore, even suffering from the chronic disease that need long-term medication treatment, they still make effort to have less drugs. Moreover, one interviewee mentioned that one medication that he took was so severe side effect, which even cause stomach problem after taking for a period.

Compare to others, forgetfulness is the most chose for low adherence. 63.3 % participants agreed that they forget to take medication sometimes, while only 18 of all have missed taking for reasons other than forgetting. When asked the frequency of forgetting, 11 people reported of never/rarely forgetting, 22 people reported of forgetting once in a while, 24 people reported of forgetting sometimes, other 7 and 1 people reported of forgetting usually or all the time. It was found from the interview study that the situations behind forgetfulness are various. The most responded one is the waiting time of taking medication after meal. In many cases,

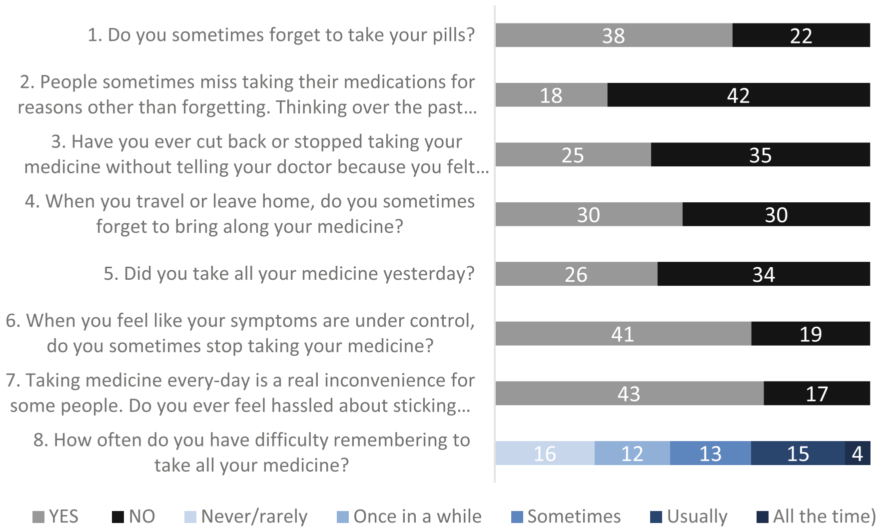


**Fig. 1** Results of each question from the MMAS-8

People were indicated to take drugs after around half an hour of a meal. Nevertheless, in this short period, they may get attracted to other things then just forget or postpone the medication taking.

Environment will influence the adherence. The data shows that 50 % of the first study participants agreed that they have experience of forgetting to taking medication when leaving home or on traveling. The result was proved by the most of the interviewees in the interview study as well.

## 3.2 Disease and Therapy

From the questionnaire study, it was reported that top four disease categories are Ophthalmology and Otorhinolaryngology disease (50.0 %), Digestive System disease (46.7 %), cardiovascular and cerebrovascular diseases (43.3 %), and orthopedic diseases (41.7 %). The elder patients who have more than three disease accounted for 48.3 %, and all participants who over 80 years old have at least three disease. Extreme case is up to seven different diseases in the age over 70 years old.

Except for the normal therapy, Traditional Chinese Medicine (TCM) therapy is also accepted and adopted in many cases. 38.3 % participants have taking the traditional medication, while only 6.7 % among them are chose to only having TCM therapy.

43.3 % of the participants are satisfied to the current therapy regimen, but 65.4 % people among them showed low medication adherence as well. In the interview, three interviewee reported to be the unsatisfactory case because of extreme side effects, slowly pharmacodynamic effect, high frequency or dosage. The one who was high medication adherence was because of the good physician-patient relations.

## 3.3 Health Care and Physician-Patient Relations

For the special therapy satisfied case mentioned before, the interviewee said, “I usually go to see him once per month and I have a regular doctor that I trust for more than two years. My doctor will adjust the medications according to my feedback of preceding medication and the season as well. He is the person who will explain the disease/medication very carefully and repeat his words to make sure I can understand completely. We have very good communication with each other and even become friends at social media platform. Sometimes, I don’t need to go to the hospital, just leave him a message then he will reply to answer the questions.”

In the questionnaire, 64 % participants regarded the physician-patient communication as the relationship between superior and subordinate, while other 28 % consider the relationship as partner or friend. Medical skill, reputation, attitude are the three main factors that participants consider of a doctor. Moreover, 81.7 % people choose to have the same doctor every hospital visiting. However, there are still more than half of the people (55 %) indicated they would judge the given recommendations according to their own feeling of the body condition and would not stick to doctor strictly.

In the care provider interview, it was showed that not all the care provider have the same understanding of medication adherence. The doctor and pharmacist were the people have more knowledge rather than the nurse. The doctor gave the medical guidance, which include medication usage, side effect, diet, physical exercise, lifestyle advices and so forth. While the pharmacist focused on the information more related to the medication itself.

### *3.4 Living Situation and Health Related Lifestyle*

Among all the questionnaire participants, only 17 % of them were living alone, while the others were living with family members together. The most of cases were living with spouse without children (40 %) or with children (31.7 %). 18.3 % people have the need of family reminding medication taking. Most of the people (73.0 %) have experience of physical exercise, but 6 % of them adhere to exercise every day. It was known from the interview that physical exercise need to be appropriate arranged depending on the individual physical condition especially for the elderly. Simple walking is exercise intensity sufficient for some elder people. 65 % people trust the health-related information offered by professional physician, other approaches including Internet, TV-program, newspaper and magazine. Information include diet, drug usage, exercise, living habit and mental health. 13.3 % participants have been using patient-support tools such as pill case or reminder alarm.

## 4 Discussion

### *4.1 Educate and Motivate the Patient*

Reasons of medication non-adherence are various. However, the ultimate and the most challenging one is lacking of motivation. non-adherence and adherence are both behaviors, which are affected largely by the related knowledge and motivation [15]. To improve the adherence, sufficient adherence knowledge and effective motivation are essential for achieving the goal.

Knowledge related to medication adherence including disease-developing course, disease effective management, related prescribing medication and so forth [16]. In the study, it is found that the knowledge level of elder patient is different individually. Although the result of knowledge level showed no strong correlation with the age. The result showed that the relative younger patient (<70 years old) are familiar with more information accessing approaches such as Internet, while the older patient (>70 years old) are sticking to the traditional medium such as newspaper and TV-program. Therefore, the channel or platform of acquiring information is different according to personal preference, which can be one of the design insights. Motivation related to the medication adherence is affected by the beliefs on medical condition, the value of the treatment regimen and the self-confidence of following it [15]. In the user study, some elder participants defined the chronic disease as the one have rarely possibility of recovering to normal. Then the medication just an approach to maintain the current body condition. Other people indicated that the medical condition is in a lasting change thing. They would cut back or stop taking mediation without telling doctor once they felt the disease symptoms are under control. Moreover, the results showed that less than half of the patients are satisfied with their treatment regimen. Effect of medication itself is one reason behind, but the situation is more relate to the care providers.

### *4.2 Spread of the Care Provider*

In China, people trust the health-related things provided by professional care providers rather than any other resources. Among all kinds of care providers, people would like to trust doctor other than pharmacist or nurse since the doctor takes the most of the work in the medication treatment process. The title of the doctor matters when choosing doctor for condition with serious believes. Specialists are the doctors in higher occupational title with advanced medical skill, experience and higher quality of outpatient service. However, these people are relatively few in the real situation. Therefore, spreading the effective and feasible experience of different care provider (especial all the doctors) would benefit more patents. Care providers with different job position, including doctors, pharmacist and nurses, are in the same medication treatment chain. Therefore, they need to have the right understanding and sufficient knowledge of medication adherence. While, the answers given by care providers in the interview study were not completely the same.

Every patient is different. Care providers need to evaluate each one individually, define the most influenced factors of the medication adherence and make the plan of the interventions. Suggestions of improving physician-patient relations include spending longer outpatient time, setting up regular doctor visiting schedule, assigning patient to a regular doctor, providing detail information related to the disease and regimen, adjusting medical recommendation based on feedback, speaking slowly and repeating important words, interacting with the patient in social media.

## 4.3 Design Perspective

Patient-support design can be an effective solution for improving medication adherence. Design can help to increasing medication-taking behavior by supporting physical ability and psychological factors, such as motivation and knowledge.

Design aiming for supporting physical ability is a direct way for increasing medication taking in somehow. Taking visual impairment as an example, it is known that low vision can affect a person's ability to read medication specification and prescription labels. Therefore, supporting design can aim for using large print and high contrast color on labels and written materials. Moreover, for the elderly who have impaired mobility as hands dexterity, the patient-support design can focus to develop easy-to-open medication containers or packaging.

As mentioned above, effective motivation is essential for improving adherence. In the study, it is found that the elder patients were less motived by medication itself, but more motivated by other positive things, such as the pleasure of physician-patient relations and fear of the medical condition. In the study of psychology, Dr. BJ Fogg highlights three core motivations with two sides each, which are sensation (pleasure/plan), anticipation (hope/fear) and belonging (acceptance/rejection) [17]. In this way, other things such as pleasure of family care, fear of overstating non-adherence consequence, acceptance of peer pressure can be considered as possible motivations for improving adherence.

Adherence is a behavior, which is rarely a simple and single dimension event. As the Fig. 2 shows, Dr. BJ Fogg have created the Fogg Behavior Model (FBM) with

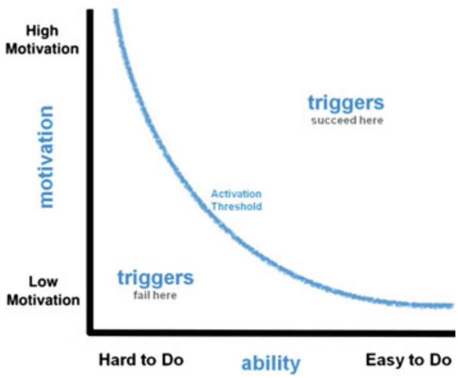


**Fig. 2** Fogg behavior model (FBM) [17]

motivation-ability-trigger three indispensable elements [17]. Trigger can be renamed as cue, request, call to action that aimed for tell people “do it now”. In the study, it is found that the elderly are doing so by making the medication prominent in the home environment; by setting up the special medication-taking alarm; by combining schedule into their own daily living routine (meal or habit).

## 5 Conclusion

With age increasing, people tend to suffer more diseases and take more medications. However, the medication adherence is low among the elder patient in this study. Almost no participants have heard about the idea of medication adherence, but some of them have the knowledge related to it in somehow (Table 4).

Reasons of adherence or non-adherence are various and different individually. The most agreed one for non-adherence is forgetfulness. However, the situations behind forgetfulness are various as well. The most responded one is the waiting time of taking medication after meal. Other non-adherence reasons including adverse medication effect, symptoms are under control, negative attitude towards medication, high frequency or dosage and environment changing. In the study, good physician-patient relations is the most motivated reason of adherence. Other reasons of adherence include fear of the medical condition and trust on the specialist. Therefore, educating and motivating the patient, spreading of the care provider are the two concluded design strategies for improving medication adherence.

People always are changing. Patients’ attitude and behavior towards medication are influenced by various factors, and are changed sometimes, which make the people in design need to consider the medication adherence as a dynamic, systematic process and develop the solution according deep understanding of both medication adherence related factors and elder patient lifestyle.

**Table 4** Reasons of adherence or non-adherence

| Reasons of non-adherence | Reasons of adherence |
|---|---|
| Forgetfulness | Good physician-patient relations |
| Adverse medication effect, symptoms | Fear of the medical condition |
| Negative attitude towards medication | Trust on the specialist |
| High frequency or dosage | Educating and motivating the patient |
| Environment changing | Spreading of the care provider |

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# Design Ideation and Prototyping for Interactive Footwear: A Report on the Foot-Wearables Design Workshop

**Matthew Swarts**

**Abstract** This paper presents the process, output, and outcomes of a workshop on interactive foot-wearables. The first half of the workshop was largely devoted toward creativity through an enactive model of group play. In the second half participants joined together to form production groups with subgroups to maximize the expertise and skillsets of the participants. The result was a rich set of concepts and the deep development of a functional prototype.

**Keywords** Interactive products · Foot-wearables · Co-creation

## 1 Introduction

Wearables have become a more popular subject in the interactive design space with the introduction of smart glasses, watches, and clothing. One type of wearable on the feet of legs, which we call 'foot-wearables', seems to have had less development than other forms. While there have been several foot-wearables in both the research and the commercial spheres [1–3], most have been focused solely on either for tracking fitness performance, for rehabilitation, or for training. The primary purpose of this workshop was to explore more deeply the design space of foot-wearables to reveal what potential exists. The secondary purpose was to develop a working prototype and appropriate testing methods. Lastly, we wanted to engage participants consciously in collective imagination using a model of enaction for creativity [4].

In our model of enaction, we used the term 'unclamping' to refer to a process in which each person detaches from their current working model and mindset and the term 'clamping' to refer to the process of everyone collectively engaging in the creation of and latching onto the same world model. As most of the participants were from the same city, the first 'unclamping' activity was to leave that city and fly

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to another. Once arriving in the host city, a series of 'clamping' and 'unclamping' activities assisted in keeping the focus and intensity of engagement high throughout the workshop.

In the first half of the workshop we spent much time on collective divergent thinking. After generating several concepts, we used a cascading sequence of approaches to collectively converge on a smaller and smaller set of concepts for implementation. In the second half of the workshop we took one concept and implemented both physical and interactive prototypes along with user study and market research method guides.

## 2 Divergence

The first three days were devoted to collective divergence. The primary design method for this was the card sort [5]. In the first step participants were asked to use the left half of a post-it note to write or draw something you can do with foot-wearables. Participants were given only a few minutes to produce as many notes as possible with an emphasis of quantity over quality. By recording concepts onto physical materials, the mind is less prone to being blocked by lingering thoughts. In the second step, post-it notes were shuffled and re-distributed. Participants were asked to use the right side of the post-it to respond to the left side as a prompt. Again with only a few minutes, participants were urged to produce as fast as possible in order to bypass the decision making restraints of the prefrontal cortex. The following step was to split the notes in half, and then to shuffle them again.

Participants took each of the half sheets and attached them to the wall. They were asked to position the notes near similar notes. This was done without verbal communication so as to delay as long as possible the formation of any categorization or structuring, which could potentially restrict future idea generation. For about an hour we silently attached and reattached notes to the wall, allowing a form to slowly emerge, see Fig. 1. Different colored notes were used to label and

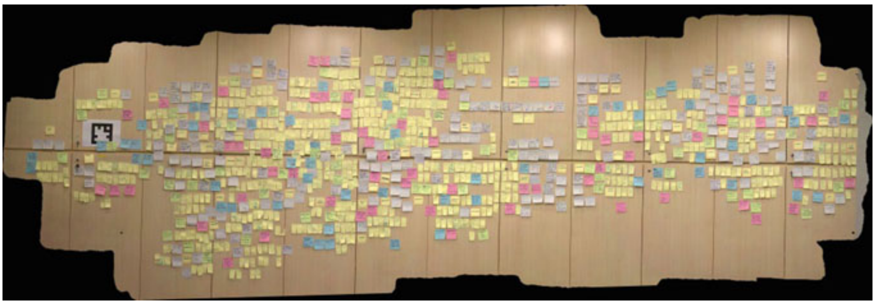

**Fig. 1** Output of the card sort activity. Initial ideas are *yellow notes*, cluster labels are *red*, opportunities are in *green*, problems in *pink*, insights in *blue*, and prompts in *grey*. The center contains the prompts for the nine pitches

characterize zones. Guided by one of the workshop organizers, clusters were collectively suggested and named. Once this was done, we added notes for opportunities, problems and insights. Following more discussion we added design prompts.

## 3 Prompts, Pitches, and Briefs

The result of the card sort was a set of design prompts. Participants were allowed to vote using seven stickers to indicate their preference for a prompt. Based on the voting, the top nine prompts were isolated for further development, see Fig. 2. The following are the nine prompts along with one additional prompt that was highly rated.

1. How do we leave footprints behind that only some people can see?
2. How can we use feet at the input when hands are busy?
3. How do we be become adventurers?
4. What if our shoes could sense other shoes and react?
5. How might we help amputees feel the grass beneath their feet?
6. How can my foot-wearable make me money?
7. How might we support behavioral modification?
8. What if we could run on the spot with a special shoe?
9. What if we create a shoe chassis that can support modular personalization?
10. What if dance patterns could unlock systems?

The eighteen (18) participants were split into nine (9) teams of two (2). Each team was randomly assigned one of the top nine prompts. Each team had an hour to develop a pitch based on the prompt. The contents of this first phase were digitally documented and shared online for all teams to see. Each team presented their findings and pitch. The following day the same teams of two were randomly assigned a different prompt. Incorporating the previous team's efforts, these teams developed a more complete pitch over the course of an hour. These pitches were then presented to all participants. Three (3) were selected for continued development.

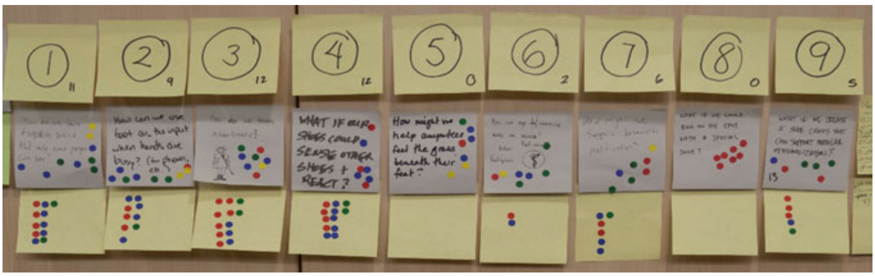


**Fig. 2** The top nine prompts arranged in order of the number of sticker votes

**Table 1** Classification of attributes of the three briefs

| Project | Temporality | Scope | Cadence | Emotion |
|---|---|---|---|---|
| Adventure | Asynchronous | Public | Moderate | Curious |
| Footprint | Asynchronous | Personal | Low | Intimate |
| Foot-to-Foot | Synchronous | Personal | High | Playful |

At this point in the workshop participants were grouped into three production groups: form, function, and story. The form group was subdivided into the industrial design team and the soft goods team. The function group was subdivided into the software team and the hardware team. The story group was subdivided into the research team and the strategy team. This was done to maximize the skillsets of the selected workshop participants in producing useful output and outcomes.

The six (6) members of the story group developed the three pitches into design briefs. The design briefs contained a description of the design problem, background information, a proposal, requirements, deliverables for the minimum viable product, and initial research questions for evaluation. The first brief was Adventure Footwear—a wearable device that can sense a given waypoint and indicate the direction of travel to it, indicate that the waypoint has been reached, and then find and indicate the next waypoint until the final destination is reached. The second brief was Footprint Tracking—wearable devices that are linked together to support authoring and discovery of spatially positioned activities to enable and enhance connections between specific people or groups of people. The third brief was Foot-to-Foot Communication—a pair of wearable devices that connect parent to child by transmitting haptic representations of the child's patterns of steps. Table 1 shows how the three pitches differ from one another in terms of temporality, scope, cadence (i.e. how frequently the notification/interaction occur), and emotion.

## 4 Prototype Implementation

While the story group developed the three design briefs, the form group and function group developed materials that were likely to be needed for all of the briefs. All three briefs would likely use some addressable LEDs, force sensitive resistor or Hall Effect sensors, vibration motors, and inertial measurement units. In addition, each brief would require 3D models of feet and footwear along with materials to produce footwear. Once the briefs were developed, all groups decided that there was only enough time to implement one. The Foot-to-Foot Communication brief was selected for implementation as it was the clearest for which to develop a test methodologies due to the high cadence of interaction, and additionally the Adventure Footwear and Footprint Tracking were similar to existing products, reducing the impetus to prototype them.

**Fig. 3** Initial foam sheet and canvas material footwear soft goods prototypes based on the lasso shoes

The function group sorted the hardware sensors and actuators available. They also downloaded associated code libraries and produced test code snippets for each component type to prepare for integration of the hardware with the form. The two subgroups of the for form group were not as interlinked as the software and hardware teams of the function group.

The soft goods team faced with the need to produce one pair of footwear for an adult and one for a child, decided to create prototype using the model of the Lasso Shoes by Gaspard Time [6]. Figure 3 shows some of the initial prototypes using foam sheets and then canvas fabric sewn together using a blanket stitch with white cotton thread. While canvas material is durable, the edges fray easily. In a subsequent reversion, the edges were flipped inside out to conceal and control the fraying. Lacking the proper tools and materials to produce robust footwear, the team selected a commercially available shoe, based on the experience gained from the prototyping.

The industrial design team produced 3D models of feet and footwear. They used scanners and photogrammetry to create point clouds as the basis for retopologized 3D models of feet and footwear. Scanning feet was difficult, because the position of the foot when it is under a load is very different form when it has no load. The team applied an artificial load using a clear acrylic sheet so that the team could still scan the foot while under a load, see Fig. 4. Team placed markers on the feet at specific locations that are typical for foot modeling, so that we could see the differences due to loading. Figure 5 shows the output of the photogrammetry of one foot under a load. The team also applied photogrammetry to scan shoes. The 3D models were used to virtually mock up hardware placement on footwear.

The industrial design team also produced casts of two average size feet from among the workshop participants. They used alginate for creating molds from live body parts, as alginate sets quickly and does not heat up as much as other agents. Once set, the team cast the molds with clear silicone. These were useful for the soft goods and hardware teams to physically mockup and discuss sensor placement.

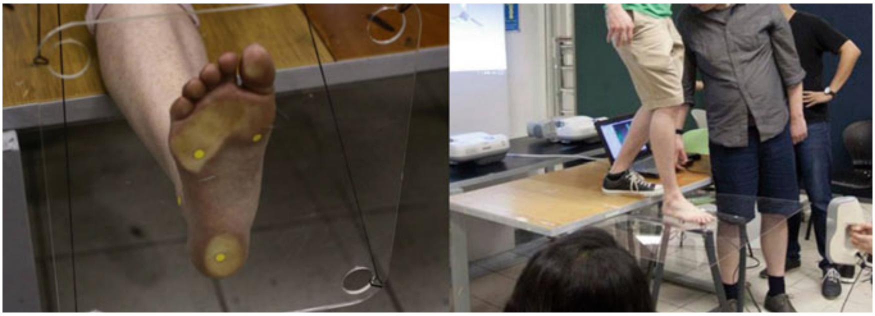

**Fig. 4** Scanning and photogrammetry process. To produce scans of the foot under a load, loads were applied using a clear sheet of acrylic

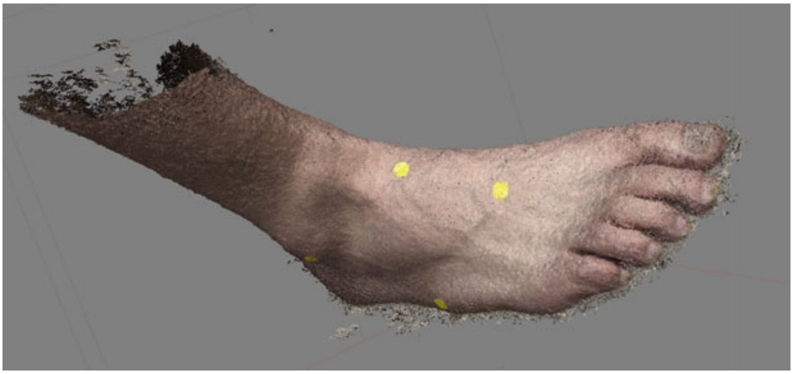

**Fig. 5** Scanning and photogrammetry process. To produce scans of the foot under a load, loads were applied using a clear sheet of acrylic

The research team performed a literature review to look for prior works and created a set of testing protocols. The core research questions were about Adoptability, Meaning, Usability, and Intimacy. For Adoptability, the question was 'How do cultural expectations affect perceptions about the adoption and use of foot wearables?' The potential for adoption is the first step in understanding if and when a product might become acceptable enough to enter the market and become viable. There were two about Meaning in how people infer situational meaning from haptic feedback from foot-wearables. One aspect is the peripheral capability of sensing vibrational feedback, while the second is about attentive meaning in the form of a game or communication state. The core question of Usability was about how foot gestures can be successfully used and overall if the foot-wearables can decrease anxiety levels for parents. Intimacy questioned the development of the relationship between the parent and child with the Foot-to-Foot Communication foot-wearable.

The research team developed a compressive plan with three components. The first component was a study to observe the use of the foot-wearable for adoptability and for sensation of the feedback. The second component was a survey on the adoptability of the product. The third component was a set of experiments involving a parent and child to evaluate the physiological responses to the system as well as the gesture learning and retention in an emergency.

## 5 Observations

The cart sort activities in the first half of the workshop effectively extracted the tacit knowledge of the foot-wearable design space, from which we believe there indeed is a very exciting potential for future design work. The final functional prototype, see Fig. 6, demonstrated the maximal use of the skillsets from all of the participants through the structure of the production groups. The production groups enabled the development of materials for physical prototyping, functional prototyping, and the development of fully formed research methodologies. The use of unclamping and clamping activities, specifically by having the workshop hosted in a different city, allowed participants to engage together. Additionally, with the participants actively aware of the enactive model of creativity, they could observe when teammates were prematurely unclamping from a clamped engagement. This helped to mitigate conflict throughout the process and facilitated an extremely satisfactory experience, output, and outcome for the workshop.

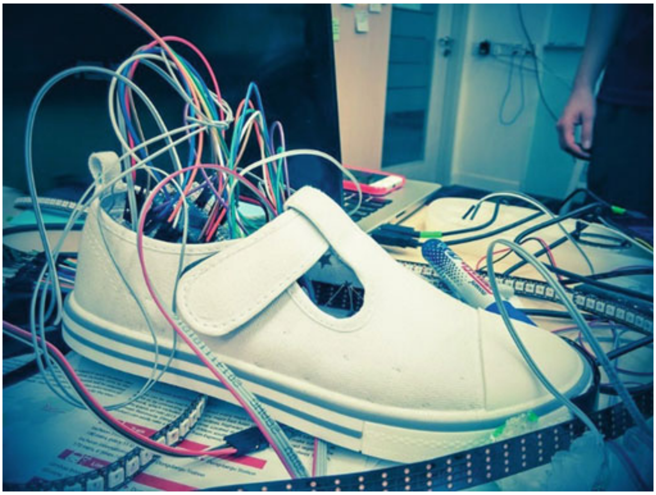

**Fig. 6** The first interactive shoe prototype that integrates the visual prototype with the functional prototype using addressable LEDs, microcontrollers, sensors, and bluetooth modules

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# Part VII
# Information Design

# Typographic Literacy: Are Users Able to Perceive What We Design?

**Daniel Rodriguez-Valero, Fernando Olivares and Alberto Pinillos-Laffon**

**Abstract** During the brand building process, the branding designers seek typographies which best align with the brand platform and its components, especially with the attributes, values and personality of the brand. We do so based on three premises: (a) our audience is capable of differentiating some typographies from others, (b) they are also able to interpret what the typography connotes and finally, (c) they are subsequently able to properly remember and associate them with the brand. The objective of this paper is to verify if these three premises—converted into hypotheses—are true, in order to equip the brand building process with better arguments and in the end, an enhanced scientific basis. To achieve this, it is necessary to create an experiment and survey a specific audience (Spanish university students with any degree—except Advertising and Design—from the Alicante area) in order to reach initial conclusions; if the results are interesting and validate the three hypotheses, then it will possible to expand the sample and apply for public funding to continue the project. For this pilot study, we relied on help from volunteer students with an Advertising degree as surveyors.

**Keywords** Brand building · Corporate typography · Visual literacy · Visual rhetoric · Typographic connotation · Typography

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## 1 Introduction and Literature Review

A logotype is not a brand. This should be remembered. However as the display of the brand name, it does have its importance. When we as designers select or sketch a typography which will make it tangible, we do this based on a series of pre-established concepts (a paradigm) which like the beliefs they are, are not entirely scientifically proven. In this paper, I will focus on three premises on which the argument is commonly constructed for any brand building project:

a) *our audience is able to differentiate some typographies from others*,
b) *they are also able to interpret what the typography connotes, and finally*,
c) *they are subsequently able to properly remember and associate them with the brand.*

If any of them are incorrect, all subsequent argument will be cancelled, with the danger which this entails. We can say that our work is built on shifting sands. For example, Bartram [1] found that designers and non-designers frequently judge typographies in a different way, hence it can be concluded that designers cannot base their work solely on their own experience and opinions but must also examine the corresponding associations of their target audience. The aim of this paper is to verify the three hypotheses and for this purpose, set up a suitable, manageable and affordable experiment.

However prior to discussing the experiment, we will revise the background of the topic to be handled. Any designer with enough experience would have no problem with any of the three hypotheses but from the academic field, they would not find too many approaches to this subject. In any typography manual and history book, they describe how each letter had cultural and national connotations, for example in Rome, the letters with a serif were associated with the Imperial script and san-serif letters with the Republican script [2], or closer examples such as the Gothic script in Germany (and by extension to the beer). In addition to this connotation possibility, very well described by Van Leeuwen [3], we add the metaphor as a tool to achieve that the typographical forms acquire their own meaning, as defended by the movement called *The New Typography*. Especially during the second half of the 20th century, it was based on a clear premise: each typeface has a personality and must express the content and the text in itself (the form follows the function). Especially since the invention of desktop publishing, the form became the first communicative plane and increased its evocative, connotative and metaphorical capacities.

> As is the case with forms, the variety of letter types is infinite, which can transmit an infinite number of images… The high and narrow letters with precise serifs appear elegant; the round, thick, san-serif letters seem cheerful, even affectionate… A letter type which provides the impression that it has been handwritten will transmit an identity of human enterprise, welcoming, not flashy [4] (p. 125).

The personality of the typography has been studied by psychology, linguistics, semiotics and marketing, however as Burt [5] and Brumberger [6] state, there is practically no objective research about the psychological aspects of design and the use of typography. In Brumberger [6] (p. 208–209) it is possible to study a detailed review of the different academic approaches to this question, at the same time, it shows that people effectively attribute a personality to each typography.

Likewise, it has also been studied that the greater consistency and relation between the typography, contents and images, the greater degree of remembrance and identification of the brand [7, 8].

The semiotics of typography by Van Leeuwen [9] provide tools to analyze the typography from its linguistic meaning. Bellantoni and Woolman [10] describe two levels of meaning for the printed letter, the word image—the idea represented by the word itself—and the typographic image which transmit a specific impression. Since typography has become democratic and is within everyone's reach, the lack of a sufficiently complex typographical grammar is made evident in each Power Point file which falls into our hands.

In summary, we face a field which is not exactly a desert but there is a great deal to investigate, above all, the degree and capacity for distinction and memory which the audience possesses about the typographies; the visual literacy has grown steadily as our contact with new information technologies has increased and we increasingly write and compose texts by ourselves.

## 2 Method

In order to validate the three hypotheses, we decided to start with a quantitative tool: the survey. Based on my training as a designer, accustomed to the execution of prototypes to validate projects, I planned to begin with a small and manageable universe, University students from the environment in which I operate—the University of Alicante—subsequently, if the results were interesting, to seek funding to convey the survey to a larger and more representative universe for the branding sector, which works with much broader audiences.

Assistance was also required to carry out the surveys and due to lack of funding, it had to have a zero cost; the natural option was to rely on students who are in their last academic year and carrying out their final degree projects. I was helped by the student, Cristina Miralles Rebollar and by fellow PhD professors and colleagues, Alberto Pinillos-Laffon and Clemente Penalva Verdú. The first is a specialist in corporate naming and the second is an expert in research techniques; they will be in charge of revising the survey from their respective fields. The result was a Final Degree Project—henceforth FDP—titled *Corporate Typographies associated with the remembrance of brands*, successfully defended in July 2015 in the Faculty of Economic and Business Sciences of the University of Alicante.

This FDP includes a survey and a small part of this survey contains the questions which can help to validate the three hypotheses described in the above section. The same universe was selected to take advantage of the results: students from the University of Alicante, excluding those who are studying in an Advertising or

**Table 1** Sample distribution

| | Economics and law | Humanities and education | Polytechnical school |
|---|---|---|---|
| Women | 9 | 8 | 8 |
| Men | 9 | 8 | 8 |

Public Relations degree because their knowledge of design, marketing, branding and typography could produce a distorted image in relation to the object to be studied. To make sure that I was making the right decision, I set up another FDP [11] to exclusively survey this collective and to cross-reference the results.

The sample is equally divided between both genders, always seeking parity since as the majority of scholars have shown [12], both genders use and interpret language in a different way. I also sought a balance between the Faculties (Economics/Law, Humanities/Education and the Polytechnical School). We can observe the distribution in the following Table 1.

## 2.1 The Questionnaire

An anonymous and voluntary questionnaire was designed in which only the gender and the studied degree were requested in order to discard the Advertising students. Several questions were reserved to support this research in the questionnaire. To validate the first hypothesis: our universe is able to differentiate some typographies from others, they were asked:

a) the name of seven typefaces.
   To validate the second hypothesis: the audience is able to interpret what the typography connotes, the surveyed parties were asked:
b) why they selected a font to compose a text;
c) they were shown nine different typefaces and they were asked to evaluate them as formal or informal, dynamic or static, simple or complex and modern or classical.
   To validate the third hypothesis: the surveyed parties are able to subsequently remember and correctly associate them with the brand:
d) they were shown six typefaces and asked to associate them with a brand;
e) concerning the same six typefaces, they were given three options to choose from;
f) they were shown three versions of a brand where only one of the fonts used was correct.

These three questions will also be used to validate the first hypothesis, because remembering a typography requires being able to distinguish it from the rest.

## 3 Results and Discussion

Below, the results are described for each of the six sections of the questionnaire detailed in the above chapter:

A) *Do you remember seven typefaces?*
This was an open question, where the answers were transcribed and those which had a 5 % repetition were selected. The six typefaces remembered most by the surveyed parties are Times New Roman, Calibri, Cambria, Comic Sans, Arial and Helvetica.
46 %, practically half of the surveyed parties were unable to mention seven typefaces. Curiously in the questionnaire conducted among the Advertising students (Ricote [11]), the list is very similar: Times New Roman, Calibri, Arial, Helvética and Comic sans. However, the percentage of students able to mention several names of typefaces was much higher.

B) *Why do they select a font to compose a text?*
This question was also open, hence the answers were transcribed and consequently analysed. The most repeated reason, practically by all the surveyed parties, is that *they selected it based on the person to whom it was addressed*.

C) *Evaluate nine typographies*
The surveyed parties did not have any problem separating the formal typefaces—Kunsstler (used by the sunglasses brand, Knockaround), Times New Roman, Myriad (used by Apple among others), Musa (similar to the Samsung typography), Bodoni and Gotham (used in excess in film posters and political graphics)—from the informal ones—Arsenale White (Mr. Wonderful, a Spanish brand highly successful among the young people of our country), Coca-Cola and Green Font (Heineken)—(Fig. 1).
They also had no doubts when classifying the dynamic and static typographies, assigning dynamism to the handwritten letters and the opposite to the sans-serif ones.
When they were asked to evaluate them as simple or complex, they evaluated Kunsstler (used by the sunglasses brand, Knockaround), Coca-Cola


**Fig. 1** Samples included in the questionnaire

and Musa (Samsung) as complex; consequently, the rest were evaluated as simple.

Regarding modernity and classicism, they were also no doubts nor too many differences between the genders. They classified Kunsstler (Knockaround), Bodoni and Green Font (Heineken) as modern. Women added Arsenale White (Mr. Wonderful) to the selection (Table 2).

D, E) *Associate the typography and the brand*

In the first brand, 70 % could identify it as Vodafone, the remaining 30 % coincided in error, identifying the typography as Adidas and Facebook. When they were given three options, the percentage rose to 80 % (Fig. 2).

In the second brand, Telefónica, 80 % correctly guessed the test; curiously, those who failed it mentioned Movistar, a brand from the same company. When they were given three options, the percentage rose to 100 %.

In the third brand, Ford, 46 % were able to associate it in a spontaneous way; the percentage of men (56 %) is significantly higher than the women (36 %). Fortuna and Barbie were the most frequently repeated incorrect answers. When they had three options, the percent was 74 %.

In the fourth brand, Decathlon, 54 % of the surveyed parties correctly associated it; with a major difference between genders (40 % women and 68 % men). None of the wrong answers reached 5 % repetition but the majority of the brands were sports. When they were shown three options, the percentage rose to 90 % (80 % women and 100 % women).

In the fifth brand, Adidas, the correct guesses were 100 %.

**Table 2** Typographical qualification made by the surveyed parties

| | formal | informal | dynamic | static | simple | complex | modern | classic |
|---|---|---|---|---|---|---|---|---|
| Arsenale White | | ■ | ■ | | ■ | | ■ | |
| Kunsstler | ■ | | ■ | | | ■ | ■ | |
| Gotham | ■ | | | ■ | ■ | | | ■ |
| Times | ■ | | ■ | | ■ | | | ■ |
| Coca-Cola | | ■ | ■ | | | ■ | | ■ |
| Myriad | ■ | | | ■ | ■ | | | ■ |
| Musa | ■ | | | ■ | | ■ | | ■ |
| Bodoni | ■ | | ■ | | ■ | | ■ | |
| Green Font | | ■ | ■ | | ■ | | ■ | |


**Fig. 2** Typographies shown in the questionnaire

In the sixth brand, Burger King, the percentage was 50 %, where Tiger was the most frequently repeated brand among the wrong answers. When they were given three options, the percentage rose to 80 %.

F) *Correct logotype*
In this test, they were shown three logotypes from Hello Kitty and only one—the third logotype—was the genuine one. 54 % of the surveyed parties correctly guessed the version; the errors were equally divided among the two remaining options (Fig. 3).


**Fig. 3** Logotypes shown in the questionnaire

## 4 Conclusions

Below, the answers obtained in the questionnaire are analysed in order to continue with the discussion and conclusions:

When the surveyed parties were requested to name seven typefaces, only 54 % were able to do so; the low percentage proved to be surprising hence in the future, we can request up to a maximum number of seven and measure the degree of remembrance. The six typefaces remembered most by the surveyed parties are Times New Roman, Calibri, Cambria, Comic Sans, Arial and Helvetica. There are no surprises in the first five since any person with experience in Office IT systems has used them at some time. It is curious that Helvetica has appeared in the list, since it is only installed by default in the Apple computers. In future questionnaires, it would be interesting to determine the proportion of the users of each platform in order to cross-reference the results. In any case, the answers indicate a certain degree of typographical literacy which is the result of the surveyed party's daily contact with the digital publishing tools. In this question, the hypothesis is not valid since it expected a higher degree of remembrance and that a higher percentage would be able to complete the text. Consequently, it cannot be categorically stated that the university students are able to distinguish some typefaces from others except from a small group of so-called "system fonts", the fonts which are displayed by default in the Office programs and only somewhat more than half of the surveyed parties are able to remember them by their name.

With regards to the second hypothesis, *are they able to interpret what the typography connotes*, the sample students were asked about the reason why they select a typography to compose a text and they were requested to evaluate nine typefaces. The first question had an overwhelming answer: depending on the person to whom it was addressed. I believe that this is clear evidence that the university students understand that each typography transmits different values. Hence the second hypothesis would be validated. In the second test, they were requested to evaluate nine typefaces and the surveyed parties also had no difficulties to answer; however, the results are quite different from what was expected, since they classified formal typographies—those used by Coca-Cola and Heineken—as informal, or the Samsung typography—a grotesque san-serif font without any adornment—as complex. It is also surprising that they classified Kunsstler (Knockaround), Bodoni and Green Font (Heineken) as modern, since they are classical letters which belong to models with over three centuries of history. It clearly seems that the students assign values to the typographies but it is a concern that they are different from what the designer has projected. For the design of a future survey, it is proposed to give the test to several experts in branding design to cross-reference the results since it must be assured that the projected and perceived values coincide as much as possible. Another possible extension would be to verify if the values of the brand are impregnating the typeface of the logotype, so that a classical and formal typography such as the one used by Heineken ends up being perceived as modern and informal by the consumer audience of a brand which is displayed and communicated as modern and informal.

With regards to the third hypothesis, *surveyed parties must be able to subsequently remember and associate them with the brand correctly*, this has also been validated in the test in which the surveyed parties were shown six typefaces corresponding to six brands in which the students showed a relatively high percentage of correct guesses, especially when given three options. In this case, the degree of recognition was clearly higher than expected; the university students appear to have a high brand culture judging by the results. Only when they were shown three similar typefaces and asked to associate them with the correct brand did they have problems to guess correctly, which makes sense, if as we have seen earlier, the students have difficulties to distinguish some typographies from others but not to perceive the values of the typeface and brand.

In summary, this small experiment suggests several highly interesting conclusions for the brand creation job: *the university students had difficulties to distinguish some typographies from others and to remember them in an isolated way but not to interpret or remember them associated to a brand*. If we extend the subject of the study to a broader universe and we improve the design of the survey to prevent the recorded errors, we can provide scientific evidence which can help branding designers to improve their brand building processes, at all times knowing that their audiences will be able to interpret, distinguish and memorize them. We aim to prevent that the survey tests make reference to already existing brands so that their values do not have an influence on the answers, to compare the answers with those from a universe of branding designers and to measure the differences in order to compare what they wish to express and what others perceive. One possibility is to request a new brand from the designers group which responds to certain values and show the result to the non-designers group to evaluate the results.

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# The You-Are-Here Sign in Public Maps: A Design Study with Special Focus on Orientation and Direction Elements

**Kai-Hsin Chiu and Meng-Cong Zheng**

**Abstract** In this research we explore the characteristics of the "You-are-here" sign in contrast to the information perceived by the proband. We summarize in order to analyze and evaluate the advantages and disadvantages of the respective setups. This will allow us to find out which kind of presentation/display and which elements are best suited to evoke speedy spatial cognition and convey the information in the most efficient manner possible. The results show that human body shapes most easily evoke positioning associations, while arrows create a sense of direction. Surrounding signs with a broader area box drawing and applying a 2.5D style does not only consolidate different elements, but also highlights an effect of direction or orientation on the map. When a user is facing the map, it can be rather difficult to correctly determine the pointing direction of such pictograms, accordingly, it usually takes more time to determine its intended meaning.

**Keywords** Spatial cognitive · Orientation and direction · You are here · Sign design · Map design

## 1 Introduction

When people move around in unfamiliar public spaces, they frequently lose their bearings and sense of direction. This disorientation leads to a perceived loss of control resulting in anxiety and even fear [1]. In such situations people have to rely on at-site maps to determine their position and orientation. Previous studies are pointing out that maps are the most commonly used tools for people to attain spatial orientation, they are the result of human spatial cognition, and simultaneously they

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are also an important tool for spatial cognition; the study of maps as a tool of spatial cognition has already become core part of cartography [2]. When using maps for positioning, directions and navigation, the most important key element is the attainment a current position and orientation information. The You-Are-Here sign on maps is used to verify one's own position, furthermore it enables us to determine directions and is the first step in any route planning. The importance of the You-Are-Here sign stems from these characteristic.

Icons can be divided into six categories according to their function. Among these are positional and navigational You-Are-Here icons providing comprehensive, local information, assisting users to verify their current position and understand the vicinity and related facilities. At the same time design elements such arrows, text, symbols and colors offer further assistance to understand movement routes and identify destination directions [3]. Basis for the design of meaningful icons needs to be a common cognitive consensus. Through analysis and according adjustments icons convey cognitive context and meaning in order to reduce cognitive error between message and recipients' perception. And yet, everyday examples and some researches reveal show the still existing problems with You-Are-Here signs. Many You-Are-Here signage examples currently in use still fail to serve their purpose of speedily conveying positioning information within the map, because design elements utilize information-insignificant characteristics in regard to color, size or style. Most You-Are-Here signs also lack clearly recognizable direction characteristics, making it impossible for the user to tell on which side of the path he is actually located, resulting in disorientation. Especially in map designs using the oft-seen 2.5D map shapes combined with You-Are-Signs this poses a serious issue when it comes to positioning and orientation. Therefore this research explores the relation between the You-Are-Here sign appearance and the information people draw from it. This is done with the help of experiment records and semi-structured interviews which we then summarize in order to analyze and evaluate the advantages and disadvantages of the respective setups. This will allow us to find out which kind of presentation/display and which elements are best suited to evoke speedy spatial cognition and convey the information in the most efficient manner possible. And finally we will layout our "You-are-here" sign design improvement suggestions, hoping that these findings can enhance travelers' wayfinding results and overall spatial cognition within public spaces.

## 2 Methodology

This research is split into two experiments, each one of the experiments is divided into three stages. The first experiment is a user spatial cognition survey based upon pre-existing You-Are-Here signs. Main purpose of this survey is to analyze user cognition behavior with different You-Are-Here signage sets. The second experiment is in fact a continuation of the first survey experiment. By analyzing the the probands' actual decision making process based on You-Are-Here signs in the map, we shall find out their respective orientational effectiveness and relevant design conditions. For both experiments we used Taiwan's most representative 2.5D indoor floor plan, namely that of the Taipei Main Station, as reference blueprint. During the entire course of the experiment we used film cameras and voice-recordings to keep precise record of questions/answer modules and user descriptions. This comprehensive material was the basis for our research to develop "You-are-here" signs with most effective form and function at the same time.

### 2.1 Experiment 1

First of all we collected 92 design sets of domestic and international You-Are-Here signs. Then we asked the probands to choose 11 (12.5 %) of them, which they felt to have the best position and direction characteristics. They were also required to rank them according to superior functionality, and give information for their decision. Secondly probands were asked to draw their own You-Are-Here signs which they believe would best represent positioning and orientation. After which they would explain their reasoning. In the end, after analyzing the results, a most effective You-Are-Here design and respective conditions were defined. There were 8 male and 8 female probands, accounting for a total of 16.

### 2.2 Experiment 2

The selected top 11 sign designs of Experiment 1. are fitted with designated English letters on every floor map. Now the probands are asked to determine the letters and respective orientation. To avoid varying display angles of the You-Are-Here signs which would impact test results, signs are shown from three pre-defined angles. There is a total 36 agenda items. After the experiment is done, each false answer of the probands is being reviewed together, and an explanation and reason is give for each answer. In the end, most effective You-Are-Here design and respective conditions were defined based upon the answering time and amount mistakes. There were 8 male and 8 female probands, accounting for a total of 16.

## 3 Results

### 3.1 Results of Experiment 1

**Ranking analysis**

After collecting each probands' Top 11 ranked set of You-Are-Here designs from the total of 92 sets, the results will be consolidated by total amount of votes and accumulated rank. An evaluation index is created with the total ranking score on the x-axis and the total number of votes on the Z-axis, delivering the weighted score ratio of all 16 probands. Find the ranking method below (1). We have arranged ranking according to maximum amount of votes received. Lower numeric rank indicates higher scores. Refer to Table 1. As Y5 and Y6 attained the same rank 5, we actually end up having 12 sign sets in our Top 11 ranking.

$$X * Z/16 \tag{1}$$

In Table 1 we see that 3 of the You-Are-Here sign design elements among the Top 11 are made of human forms; 6 consist of arrow elements; and 3 display shoe/footprint elements. Therefore we can safely conclude that it is in particular design elements such as human forms, arrows and feet/shoes that create immediate cognitive potential in regard to spatial positioning and orientation, as they ignite direct spatial associations in humans. Among the Top 5 human forms dominate with ranks 1 and 2, closely followed by arrow elements and lastly shoe prints. This just reiterates the prevalence of human forms stimulating corresponding associations and spatial cognition, closely followed by arrows and shoe prints. All the human forms we find among the Top 12 icons are designed in a 2.5D/pseudo-3D style. This is a clear indication that this approach can also convey a sense of direction and movement such as arrows and shoes do.

**Oral description analysis**

In this section we analyze the reasons and decision basis upon which each proband selected their respective Top 11 position and orientation signs and the corresponding elements thereof. Based upon records of the probands' oral descriptions we can identify the 5 most prominent position and orientation elements in detail as you can see in Fig. 1.

According to the probands' information as shown in Fig. 1 there are 5 main elements best suited to display spatial positioning. These are human forms, arrows, shoes/footprints, text, color paths etc.; Accordingly, there are also 5 main elements best suited to display spatial orientation. These are human body movement, directional arrows, shoe/foot pose, line segments and dimensional shadows. As for the positioning ranking, according to the data, probands find the following 3 elements to create the most intuitive association human forms, arrows, shoes/footprints, scores are 15, 11, 9 votes. In the top 3 ranking for orientation we find directional arrows, human body moves and shoe/foot poses to be most effective with 16,12,10 votes attained respectively.

**Table 1** Top 11 sign ranking

| Rank | 1 | 2 | 3 | 4 | 5 | 5 | 6 | 7 | 8 | 9 | 10 | 11 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Icon |  |  |  |  |  |  |  |  |  |  |  |  |
| Code | Y1 | Y2 | Y3 | Y4 | Y5 | Y6 | Y7 | Y8 | Y9 | Y10 | Y11 | Y12 |

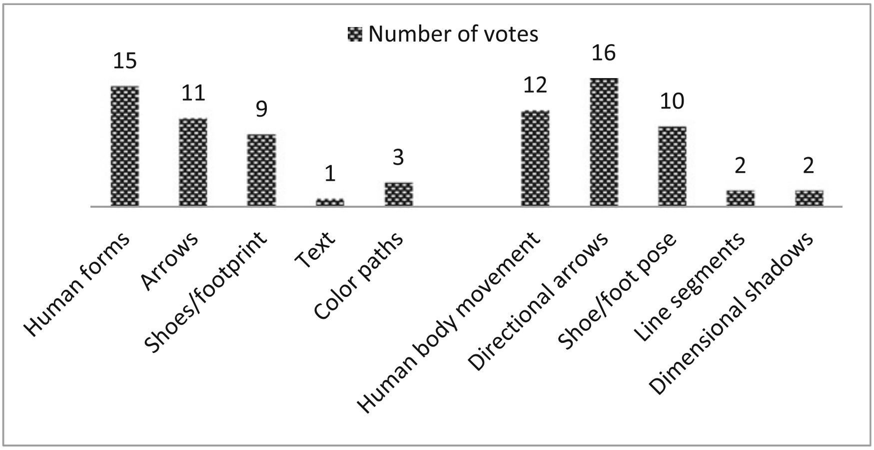



**Fig. 1** Position and orientation elements data

The probands' oral description records also allow for further analysis of the cognition pros and cons of the Tope 11 icons. Y1, Y2, Y11 etc. consist of human forms and range indicative elements on the bottom and are designed in 2.5D-style, which make them appear more apparent on the map, thereby being better suited for positioning purposes. But the arrow element in icon Y1 seems too thin and too long, leading people to misinterpret it as a shadow. While the arrow shape in icon Y2 is overly complex, and might easily confuse users at a short glance, the shadow element does not serve a indicative purpose and is therefore unnecessary. The arrow element in Y11 is not sufficiently visible, so users have to rely the human limbs' movement as indicator for direction, leaving room for improvement. The round range element on the bottom of icon Y3, does not only improve visibility on the map, but also arranges each element very well, while highlighting the direction indicative function of the arrow. The advantage of icon Y4 over icons Y6 and Y8 is its clear and simple footprint shape, why the latter two use more complex and less clear elements; the dynamic offset arrangement of the shoes strengthens the visual forward movement impression, and is hence better suited then the juxtaposition. The footprint's outer shape in icon Y8 seems rather fragmented and less clear, resulting in a certain vagueness of direction. The arrow shapes of icons Y5, Y7, Y9 are all simple and clear, creating an ideal orientation effect. Nonetheless, the size of the arrow element in icon Y9 is rather small and it displays an unneeded circle element surrounding it, making it more difficult and complex. The icon Y10 incorporates explanatory text and a clear directional arrow element, clearly communicating its meaning allowing for easy orientation. Finally, icon Y12 makes use of a rather uncommon element resembling the male gender symbol, therefore prone to cause confusion, as users might not immediately relate to it for positioning purposes. Elongated shape usually do not stand out on the map, and on top, leave users wonder as to whether their position is represented by the dot or rather where the arrow points.

**Visualized analysis**

After the 16 probands finished the ranking experiment, each one was asked to visualize in an overview drawing, what they thought to be most effective positioning and orientation icon elements in a You-Are-Here sign according to their own spatial recognition. There were no limitation on the amount of time they needed or the number of icon elements allowed to be used. Repetitive use of icon elements in different category groups was allowed. In Fig. 2 you find the visualization summary drawing.

The probands provided us with a total of 28 visualizations representing their spatial recognition concepts in regard to positioning and orientation. Icons with human form and arrow elements make for the majority, suggesting that these design approaches are best to create intuitive spatial-cognitive associations. Surprisingly, among the 28 visualizations we only find one example where footprint pose elements were used, indicating that footprint elements are no effective means to create corresponding intuitive associations for positioning and orientation purposes. Arrow elements, according to the probands' visualization mapping, should be thick and short, as to avoid being confused with compass needle images on the map, and thereby produce misleading information. Therefore keeping arrows short and thick warrants them being well distinguishable from compass needles and making them ideal and effective cognitive indicators for spatial orientation. The majority of human form elements chosen in these 28 visualizations use 2.5D designs. On the map, such elements can improve positioning effectiveness, and at the same time,

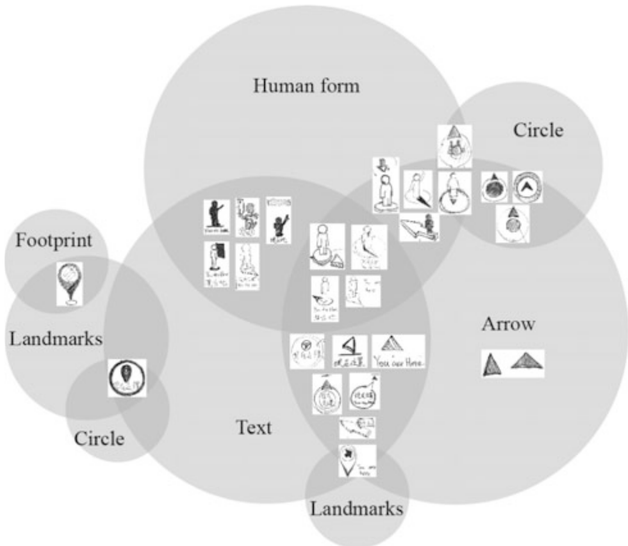



**Fig. 2** Visualized results as elements overview

create a better sense of special orientation by virtue of their human movement representation. Using human forms standing within a colored area, is also a better representation of the map reader's own, actual position.

12 of the total 16 probands also revealed in the visualization interviews, that they feel adding the text "You-Are-Here" to the You-Are-Here sign, would significantly improve effective communication of its purpose, thereby accelerating positioning speed. Another 15 probands agree that adding circular outline elements would help the overall design appearance of the sings, but above all, improve visibility of the You-Are-Here sign on the map. These interview results are also reflected in within the visualizations maps, showing 16 You-Are-Here signs with added text captures, and 21 bottom range characteristics.

## 3.2 Results of Experiment 2

**Reaction Time and Number of Errors** In this experiment the answering time and amount of errors of each proband was recorded for a set of 36 questions. Ranking was done from short to longer time-spans. Answering times and amount of errors are summarized in Fig. 3. The enframed items indicate the signs facing the map users. Of the 12 questions facing the You-Are-Here sign, 9 required a longer answering time and 8 errors orruced, exceeding those with their back to the signs. Signs exceeding 3 errors and above (including 3 times) include seven questions,

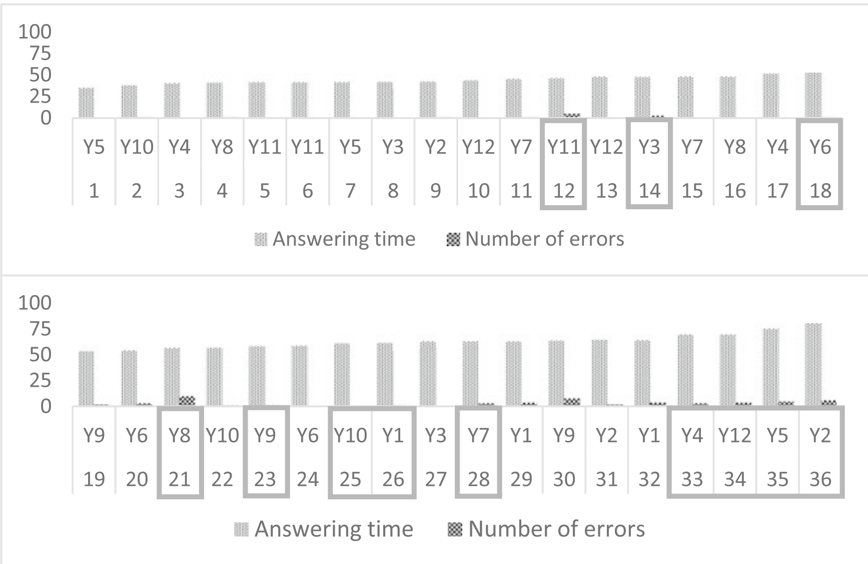



**Fig. 3** Each sign's answering time (seconds) and number of errors (times)

where the sign was facing the probands' direction. From this we can discern, that when maps are facing the user, it is more difficult for them to determine directional information, and it takes more time for users to come to a conclusion.

**Ranking analysis**

In this part we summarized all answering times and amount of errors in a weighted average for each icon element, and arranged them in a preliminary ranking, see Fig. 4. In a sequence from short to longer answering times we get the following result: Y11 < Y8 < Y5 < Y3 < Y10 < Y7 < Y4 = Y12 < Y6 < Y9 < Y2 < Y1; The error amount sequence from few to more is: Y10 < Y3 = Y4 < Y7 = Y12 < Y5 = Y11 = Y6 < Y1 = Y2 < Y9 = Y8.

For this research we place the answering time ranks for each You-Are-Here icon on the X-axis, while error ranks are located on the Y-axis. Both fractions are added up to attain score and rank of each icon. The conversion is done according to formula (2), The 1. rank gets 12 points, 2. rank 11 points successively decreasing to 1 point for the last rank. Refer to Table 2 for the score ranking according to this formula.

$$\{(12 - X) + 1\} + \{(12 - Y) + 1\} \tag{2}$$

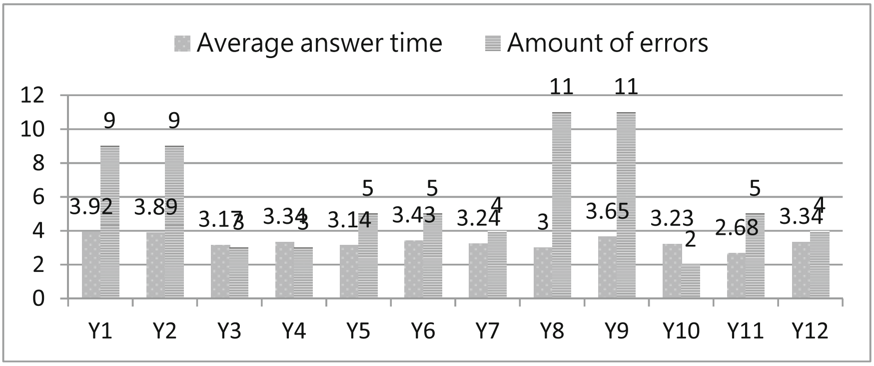



**Fig. 4** Average answer time (seconds) and amount of errors (times)

**Table 2** 12 you-are-here signs ranking

| Rank | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 |
|---|---|---|---|---|---|---|---|---|---|---|
| Icon |  |  |  |  |  |  |  |  |  |  |
| Code | Y11 | Y3、Y10 | Y5 | Y7、Y4 | Y12 | Y6 | Y8 | Y2 | Y9 | Y1 |

Among the Top 12 You-Are-Here signs of Table 2 there is only one including a 2.5D element making it into the Top 5 ranks, while the rest are plane 2D designs. This shows very clear that in the representation of orientation in You-Are-Here signs 2D designs are still overwhelmingly dominant, displaying best recognition characteristics. One reason for this fact is that 2.5D signs easily suffer from perspective distortions when trying to convey movements, making it less easy to understand or even cause misunderstandings. Some elements might be so obscured making it impossible to understand at all. When you look at 2.5D icons from certain angles, some human movement or arrow elements might not be seen which then will lead to troubles and errors in their interpretation. Furthermore, the ranking shows that arrow elements are preferred over shows/footprint elements, indicating that arrows are more effective spatial orientation representations. Arrows are better suited to create intuitive directional associations, as they are clearly pointing towards the intended direction, resulting in faster recognition. Shoes/footprints are displayed as separated items, causing a less coherent impression, and as they tend to create a radial shape, they make it more difficult to convey a clear sense of direction.

**Oral description analysis**

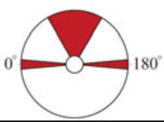
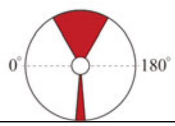
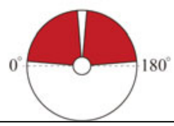
From the oral records we attain clear information about the pros and cons of the 12 You-Are-Here signs in regard to their actual usage for positioning and orientation purposes. First we take a look at icon Y8, more than 10 probands pointed out that they had difficulties to swiftly recognize which were toes and which were heel, and that they appeared too separated, making it difficult to determine the intended direction, and thus resulting in misunderstanding and error. 9 probands find the size of the error in icon Y9 to be too small, making it difficult to interpret the pointing direction, while the periphery with its black circle seems rather complicated, causing uncertainty about positioning and orientation. Another 3 probands regard the circle and arrow elements in icon Y12 to be too similar, making it difficult to understand which one should be used as positioning basis. The arrow pointing directions in icons Y3, Y10, Y5, Y7, and Y4 are very clear. Therefore answering time and accuracy is very good. Only few probands mentioned they find it difficult to swiftly tell apart forward from backward directions in icon Y4, causing confusion. And finally the 2.5D elements of icons Y11, Y2, and Y1 show flaws when looked at from some viewing angles, resulting in a number of probands not being able to identify the intended direction. Among these icons Y2 and Y1 make it difficult to tell the correct turning direction from the human forms. And the arrow on icon Y1 seems too thing and long, being easily misinterpreted as human shadows.

## 4 Discussion

In the first experiment most probands believed human shades would be best suited for positioning purposes, while arrows are ideal to indicate directions. This shows that similarity of appearance in human form icons can produce a bigger degree of attention and respective association, allowing for rapid positioning. Arrows communicate directions, guidance, instructions and similar functions, therefore arrow elements are very well suited to strengthen instructions and give users clear understanding of spatial movement. Their popularity and high visibility characteristics make them used worldwide and no matter how they are being depicted, they are always easily interpreted [4]. Furthermore, more than ten probands in this study pointed out, that the lack of descriptive text in "You-Are-Here" signs makes it more difficult to understand their meaning in a short period of time. This shows, that humans still prefer text descriptions alongside pictographs to give them a quick reassurance of their intended meaning. Chieh-Hsin Tang also pointed out that icon signs should incorporate text as well as pictographic elements in a mix to optimize recognition accuracy and perception time [5]. Therefore, in future and redesigned icons both elements should be applied to clearly communicate the underlying meaning they are intended to propagate, making it easier for people to accurately and quickly understand the provided information.

In Experiement 2 most probands spend a longer amount of time to interpret the positioning icons, and the amount of errors was considerably higher when facing with the back to the indicated direction. This shows that most people are used to a situation where their own orientation is in par with the map orientation, allowing them to make quicker and more accurate assessments. Most probands also pointed out that with 2.5D icons they had difficulties to understand from which angle the icons pointed which direction (Y1, Y2, Y11). When probands shared their experiences with the researchers, they found out that when icon Y1 was turned by 60–120 degrees the human form made it impossible to the pointing direction of the arrow, at 355–5 and 75–185 degrees the arrow was easily confused as shadow, making it impossible to determine directions (Table 3); Icon Y2 had similar issues

**Table 3** Styles and angles of unrecognizable directional icons

| Code | Y1 | Y2 | Y11 |
|---|---|---|---|
| Icon |  |  |  |
| Angle range |   |   |   |

as icon Y1, at 60–120 degrees the arrow could not be seen. Furthermore at 355–5 and 175–185 degrees the arrow appeard shorter in perspective, causing people to simply ignore it altogether (Table 3). As for icon Y11, at around 5–85 and 95–175 degrees, it was not possible to clearly tell direction angle of the human movement (Table 3). Therefore in the future it is important to test various usage angles of 2.5D designed You-Are-Here signs, or implement other You-Are-Here sign elements, in order to avoid loss of information when viewing angles are switched.

## 5 Conclusion

In this study we found out that human forms, arrows, shoes/footprints, circles and other pictographic elements can produce self-positioning associations. Furthermore, pictographic elements of human movement, directional arrows, shoe/footprint poses, line segments and shadows conveying orientation, are well suited to induce positioning associations with users. As human form icons are more similar to ourselves and we humans can relate better to them, these You-Are-Here elements are most easily and swiftly prompting positioning associations. Second are arrows and shoes/footprint elements. As for orientation, arrows offer an inherent sense of direction, guidance and instruction, it is exactly for these reasons that they create strong directional associations and immediate resonance, making them ideal icon elements for related signs. Second are human forms and shoes/footprint elements. Interviews with the probands also revealed the importance of additional explanatory texts as elements in "You-Are-Here" signs. Text not only reconfirms the intended purpose, but also increases recognition speed and accuracy of the conveyed meaning. From above research of different icon elements we arrive at the following conclusions for future signage design approaches: Human shape elements are best suited for positioning purposes, while arrow elements are ideal for orientation purposes. Furthermore, we suggest also to add text annotations, in order to optimize recognition speed and accuracy for users. At the same time, according to the experimental test results and probands' interviews, applying peripheral areas around the main element or using 2.5D pictographs may greatly improve the signs' visibility within the map, making it easier to find one's position. Additionally, by dividing signs in clear-cut areas, increases the overall design integrity and clarity. Probands also pointed out that the following suggestions can greatly improve functional effectiveness of orientation sign elements: human forms including four limbs and clothing, compass needle shaped arrows, and dynamically offset shoes/footprints.

The second experiment revealed the probands' difficulties to accurately determine the correct pointing directions in reference to their own orientation with a short period of time. Therefore in future You-Are-Here sign designs, it is of upmost importance to assume the users exact position in relation to the map orientation, in order to allow for swift and accurate map reading results. Furthermore, it is advisable to adhere to conventional 2D pictographs rather than 2.5D ones. As our research shows, elements on 2.5D pictographs may easily misinterpreted or "disappear" when looked at from certain angles (refer to icons Y1, Y2, Y11 etc. on You-Are-Here signs). Therefore particular attention needs to be paid to the visual design angles, or they should be combined with other elements for maximum clarity.

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# Study on Interface Design for Smart Phone Based Indoor Navigation Under Special Consideration of Information Judgment by the User in Emergency Evacuation Scenarios

**Ching-I. Chen and Meng-Cong Zheng**

**Abstract** In disaster emergency situations, it is vital to guarantee swift movement and evacuation routes, and as such, this is an important issue for public design. Purpose of this study is to optimize the mobile navigation interface design for emergency evacuation situations under special consideration of psychological pressure, and provide for a most efficient route of escape. For this study we used various indoor and outdoor navigation systems available on the market, and conducted experimental research focusing on their major differences in interface design. The results show that interface designs with the least amount of information load are also the fastest and most effective ones.

**Keywords** Emergency evacuation · Smart phone navigation · Interface design · Information judgment

## 1 Introduction

With the continuous progression of urban development, people increasingly rely on the convenience of underground public transportation. Lacking an advanced systematic program of safety measures and evacuation guidance provisions within such areas, such as the Taipei subway and its extensive underground mall, inevitably will result in significant casualties in an emergency disaster situation. Particularly in underground spaces common escape behavior decision-making undermines the ability to find the safest and fastest route of escape. The wide-spread

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use of smartphones providing internet connectivity, built-in sensors and powerful multimedia capabilities are currently the only individually portable solution allowing to provide for personalized escape routes.

Environmental psychology studies have pointed out that personal factors such as sex experiences affect way finding decisions and spatial cognition. In the design of evacuation information, we need to understand these differences of behavior before we can develop solutions for common use.

Therefore the need for an "Autonomous Evacuation" index system aid. User-oriented design concepts have already become common standard, yet, immanent individual needs are not always easily identifiable by designer. Environmental behavior studies can provide a number of scientific methods to assist designers to understand changes of behavior in differing environments and thereby enable them to control people, objects and the environment respectively and as a whole.

The simulation of an underground space water flood evacuation showed the specific characteristics of behavior in such situations [1]. Experiments with short distance routes were most successful, while evacuation failures were mostly caused by signs which could not clearly be interpreted. Despite paper-based evacuation flyers being convenient for distribution purposes, yet they suffer major shortcomings such as content limitations and updateability [2]. So in the future smartphones will replace this method as all information can be updated instantaneously. Currently there is little research available on the implementation of underground evacuation maps and the respective realization thereof, even less so when it comes to the provision of personal handheld devices.

Many built-in navigation systems in smartphone already offer interactive technologies. The interactive technology allows user to receive information and knowledge much faster. Shneiderman believes that a good interface design generates a positive experience and thereby increases usability [3]. He also pointed out interface design assessment criteria: learning time, response time, usage accuracy, memorability, subjective satisfaction. In a time of common and wide-spread smartphone use, it is essential to find interface designs that enable us to find and display accurate information, offer easy usability and an appealing user experience. The interface information has to consider different categories of safety information to be conveyed, such a route reminders and multiple alternative options. A smartphone interface which attempts to influence persons' behavior, must also consider the sequence and levels in which to guide and direct users, and how to create a natural level of operation and motivation, in order to achieve reassuring safety operations and provide accurate information.

The floor plan graphic used in this study is a simulation of the 1st Basement floor of the Taipei Main Station. All probands have been familiar with the Taipei Main station from personal experience. This was required so probands could put themselves in this public space during the experiment. Purpose of this study was to find the most suitable smartphone navigation interface design for most efficient emergency evacuations with regard to psychological pressure users would suffer under in such a situation.

## 2 Methodology

In this study, we collected domestic as well as international indoor and outdoor navigation apps currently available on the market. Very similar ones have been consolidated, resulting in a total of 7 quite different interface layouts (Fig. 1) being selected for the experiments. Design elements, such as icons, arrow styles, fonts, maps, and line styles had been simplified and harmonized by eliminating the color factor and applying a simple grey scale.

The same set of maps was used, but in order to avoid learning and familiarity of routes the map direction, route start and end point, movement direction and indicated distances were altered. As for the interface we manipulated the follow 5 features.

"Floor" display method.

"Destination" is text needed?

"Step-by-step instruction message" position on the interface.


**Fig. 1** 7 Samples

"Step-by-step instruction message" design approach.

"Step-by-step instruction message" display step progression.

In this experiment we used different interface layouts to observe the probands' attention, and test their message response time and accuracy. Purpose was to establish a statistical evaluation base to determine the most efficient interface layout. The experiments were done in the Experimental Design Psychology Laboratory of the Taipei University of Technology. We had ten male and ten female probands in an age range between 22 and 42 years. 6 probands were regular office workers, 14 enrolled students. The experimental equipment consisted of computers, camcorders, experiment record sheet, timer. In the first step the probands were informed about the experiments' requirements. The wording of this explanation was as following: "In a moment you will see a smartphone interface graphic on the left side of the screen. Please follow the text sequence on the right side of the screen and speak out which part you understand, if you don't understand an item please say (I don't know). While you speak out please use your finger to point out the position on the screen your eyes are looking at." The first four items timed with a maximum response time of 3 min. The fifth item was not timed.

My current location is __________

My target destination is ___________

My navigation system tell me now _________________

Therefore I ________________________

I have a question ______________________________

Followed by a computerized screen playback, displaying one screen at a time, with a total of seven screens. The sample graphic is placed on the left side, while the topic is located to the right. Probands were requested to look at the graphic while answering questions (Fig. 2).

The experiments were conducted with one proband at a time successively. In this research the subjects had to answer these 4 following question sets under time constraint as to simulate a decision making environment they would have to face under real-life circumstances, inducing a sense of pressure and urgency. A total of 20 test persons were to answer a set of questions about reference pictures/pictorials, including items such as "current location", "destination", "navigation message description" and "decision-making", within a given amount of time. Potential spare time allowed subjects to pose questions concerning each interface. We used the

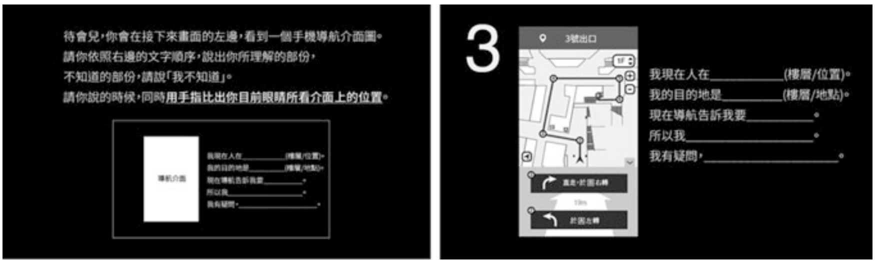


**Fig. 2** *Left* Pre-experimental interface. *Right* Set of experimental graphic

think-aloud method and asked subjects to simulate their sight of the eyes by finger pointing. During the experiment the order of the questions was randomized for each proband. After the experiment probands were asked to fill out a questionnaire and also vote for two sets of evacuation navigation interfaces they felt best.

# 3 Results

## *3.1 Cognition Speed, Statistical Ranking*

20 people responded to each sample set, items 1 through 4 were timed. This part of the statistics only compared the answering response time as shown in Table 1. After this we calculated the weighted average order and accuracy (Table 4). As each individual's train of thought and speech speed varies we did not include these times in the statistics. Proband 1's response time to a sample set might be 30 s, while Proband 2's response time might be 70 s. Therefore we did not cross-compare the absolute times as reference. We rather looked at each probands answer time individually and put them in relative order, sorted from short to long as seen in Table 4.

**Table 1** Measured, actual cognition speed record

| | Sample1 | Sample2 | Sample3 | Sample 4 | Sample5 | Sample 6 | Sample 7 |
|---|---|---|---|---|---|---|---|
| 1 | 00:12.8 | 00:36.4 | 00:34.0 | 00:29.5 | 00:24.4 | 00:39.4 | 00:34.0 |
| 2 | 01:13.3 | 00:46.6 | 01:11.3 | 01:24.1 | 00:59.0 | 01:19.0 | 01:19.6 |
| 3 | 00:28.4 | 00:47.1 | 00:38.4 | 01:01.8 | 00:28.2 | 00:47.7 | 00:39.1 |
| 4 | 01:08.2 | 00:58.5 | 00:44.3 | 00:32.3 | 00:20.2 | 01:05.6 | 00:44.4 |
| 5 | 01:10.2 | 00:56.1 | 01:17.0 | 01:23.1 | 00:36.2 | 00:59.4 | 01:19.4 |
| 6 | 00:55.4 | 01:01.1 | 01:10.7 | 02:04.3 | 00:46.9 | 01:10.9 | 01:13.0 |
| 7 | 00:29.0 | 00:30.7 | 00:44.4 | 00:48.2 | 00:24.1 | 00:34.7 | 00:49.9 |
| 8 | 00:32.4 | 00:41.5 | 00:44.1 | 01:50.6 | 01:03.6 | 01:14.0 | 01:16.4 |
| 9 | 00:32.8 | 00:59.9 | 00:46.3 | 00:45.2 | 00:33.0 | 00:44.7 | 00:46.4 |
| 10 | 00:35.2 | 00:34.7 | 00:35.6 | 00:34.3 | 00:22.2 | 00:40.4 | 00:33.2 |
| 11 | 00:29.2 | 00:54.6 | 01:03.3 | 01:06.0 | 00:26.2 | 00:57.2 | 00:32.5 |
| 12 | 00:45.4 | 00:35.7 | 01:04.8 | 00:37.9 | 00:38.5 | 01:56.6 | 01:00.2 |
| 13 | 01:32.2 | 01:31.8 | 01:14.2 | 02:17.4 | 01:03.0 | 01:21.2 | 01:17.1 |
| 14 | 00:50.3 | 00:37.3 | 00:32.2 | 00:45.2 | 00:30.9 | 00:46.7 | 00:48.6 |
| 15 | 01:26.4 | 01:10.7 | 01:08.4 | 00:45.6 | 00:42.7 | 00:58.2 | 00:26.9 |
| 16 | 00:23.7 | 00:40.3 | 00:44.9 | 00:42.6 | 00:23.9 | 00:43.4 | 00:33.3 |
| 17 | 00:36.5 | 00:41.2 | 01:16.8 | 00:57.7 | 00:26.0 | 01:22.8 | 00:31.0 |
| 18 | 00:38.3 | 00:24.2 | 00:41.6 | 00:47.0 | 00:27.7 | 00:43.2 | 00:39.7 |
| 19 | 00:27.5 | 00:21.7 | 00:25.3 | 00:23.4 | 00:19.6 | 00:42.0 | 00:19.1 |
| 20 | 00:41.4 | 00:39.6 | 00:54.2 | 01:00.5 | 00:37.9 | 01:17.0 | 00:40.4 |

**Table 2** Cognition speed, statistical ranking

| | Top three | Top two | Top one |
|---|---|---|---|
| Sample 5 | 19 | 18 | 11 |
| Sample 1 | 10 | 8 | 4 |
| Sample 2 | 10 | 6 | 3 |
| Sample 7 | 8 | 4 | 2 |
| Sample 3 | 6 | 5 | 0 |
| Sample 4 | 5 | 2 | 0 |
| Sample 6 | 2 | 0 | 0 |

Then the individual time sequences where combined into a total order as in Table 2, Table 1 one shows time each of the 20 probands spent on each set of graphs.

From this cognition speed order we can now see which set was most easily understood: Sample 5 got 7 points, second was Sample 1 with 6 points, then Sample 2 with 5 points, Sample 7 with 4 points, Sample 3 with 3 points, Sample 4 with 2 points, and Sample 6 with 1.

### 3.2 "Current Location" and "Destination", Answer Accuracy

Apart from the from a quick response time, accuracy to safely reach the target destination is of highest importance. Therefore we made a statistical record of the two items "Current location" (My current location is…) and "Destination" (My target destination is…). Only correct answers received one point. The statistical answer accuracy overview can be seen in Fig. 3. The sequential order from highest to lowest is Sample 3, Sample 2, Sample 5, Sample 6, Sample 1, Sample 7, Sample 4.

### 3.3 Decision-Making Process

This describes the decision-making process of the probands after receiving the instructions of the navigation interface. Our result record statistics are split into five items. In the first one navigation instructions were understood properly and follow after. Secondly, probands misinterpreted the navigation instructions and followed that route. The third group expressed their incomprehension. A fourth group looking at the map at their own accord and finding the destination self-reliantly. And the fifth group were hesitant (as expressed by posing questions). The statistical overview is arranged in Table 3, further pointing out if only of interface step or more than 2 (multiple, including 2) were needed.

From Table 3 we see that Sample 5 and Sample 7 each show 15 people having reached the target destination entirely relying on the navigation instructions. In each

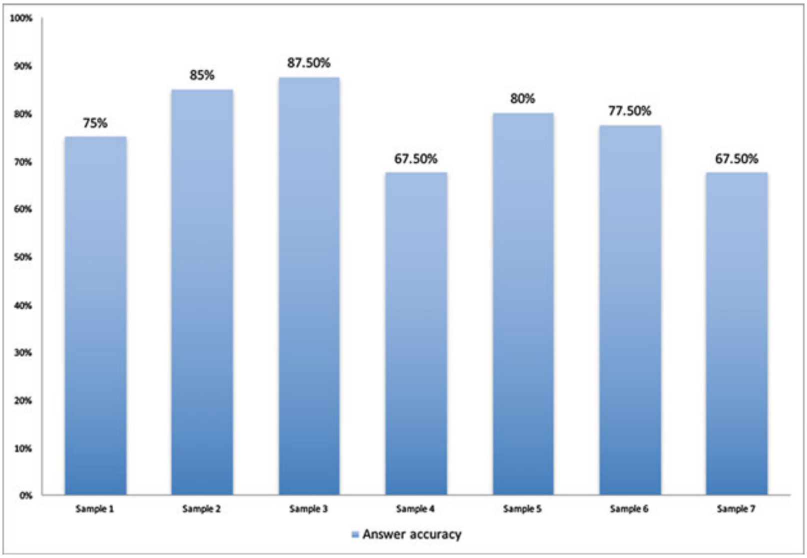


**Fig. 3** 7 Samples' answer accuracy

**Table 3** Decision-making process, statistical overview

| | Correct understanding of navigation instructions | Incorrect understanding of navigation instructions | Unknown | Self-reliant | Hesitant (raising questions) |
|---|---|---|---|---|---|
| Fig. 1-single step | 9 probands | 0 probands | 0 probands | 11 probands | 0 probands |
| Fig. 2-single step | 8 probands | 0 probands | 0 probands | 12 probands | 0 probands |
| Fig. 3-multiple steps | 6 probands | 0 probands | 0 probands | 13 probands | 1 probands |
| Fig. 4-multiple steps | 7 probands | 0 probands | 1 probands | 11 probands | 1 probands |
| Fig. 5-single step | 15 probands | 0 probands | 0 probands | 5 probands | 0 probands |
| Fig. 6-multiple steps | 12 probands | 1 probands | 2 probands | 4 probands | 1 probands |
| Fig. 7-multiple steps | 15 probands | 0 probands | 0 probands | 5 probands | 0 probands |

of these samples there were also 5 people who looked at the maps on their own and successfully reached the target destination. Therefore these two samples enabled all probands to successfully follow the emergency evacuation route. Despite 12 people following the instructions in Sample 6 successfully reaching their destination, another 4 did not reach the intended target destination, making this the sample with the highest failure rate of all 7 samples.

Four layout samples where designed with four-steps instructions to be read from bottom to top. 18 people managed to reach their destination by correctly following the navigation instructions. But 2 probands habitually followed the instructions form top to bottom.

## 3.4 Probands' Graphic/Text Cross-Referencing Proportion

The graphic/text cross-referencing of the 20 probands was statistically arrived at by interview and their pointing with fingers at locations of the line-of-eyesight on the screen. Three people responded they were relying to 80 % on the navigation instruction text. These we call the text-readers. Nine probands responded they were relying to more than 80 % on the graphic. These we call the graphic-readers. The remaining 8 people cross-referenced graphic with text. The graphic/text-readers.

## 3.5 Best Interface Poll

Following the experiment we conducted a poll among the probands, asking which interface they prefer. The best one received one point. The poll result ranking is as follows: Sample 5 received 8 votes, Sample 1 and Sample 2 each received 7 votes, Sample 7 received 5 votes, Sample 3 and Sample 4 each received 4 votes, and Sample 6 received 3 votes. The integral score was calculated by the formula below.

$$\text{Cognition speed order score} \times \text{accuracy} = \text{integral score}$$

From Table 4 we can identify the smartphone navigation interface designs with the best cognition efficiency. The best one is Sample 5, followed by Sample 1, third in line is Sample 2. Referring to the cognition speed, integral score and poll votes, shows us that these results are consistent.

**Table 4** Each samples' order, score and votes

| | Sample 1 | Sample 2 | Sample 3 | Sample 4 | Sample 5 | Sample 6 | Sample 7 |
|---|---|---|---|---|---|---|---|
| Speed order | 2 | 3 | 5 | 6 | 1 | 7 | 4 |
| Score | 6 | 5 | 3 | 2 | 7 | 1 | 4 |
| Accuracy (%) | 60 | 70 | 75 | 40 | 65 | 65 | 25 |
| integral score | 3.6 | 3.5 | 2.25 | 0.8 | 4.45 | 0.65 | 1 |
| Integral score order | 2 | 3 | 4 | 6 | 1 | 7 | 5 |
| Votes | 7 | 7 | 4 | 4 | 8 | 3 | 5 |

## 4 Discussion

Table 5 shows the statistical pros and cons of each set's graphics, data was attained by interviewing the probands.

The floor display design approach of Sample 1 could not easily be recognized, and was frequently ignored all together, or lead to a misunderstanding of the actual position on the floor. The navigation text message "Entire Route Length 117 m" (全程117 m) was regarded as not important by 80 % of the probands. The message "1F South 2 Exit" (1F南2出口) on top of the step-by-step navigation messages can easily be overseen. When this graph was the sequentially first graph in the experiment, the current location arrow symbol and the target destination symbol were easily confused with one another.

In Sample 2 the navigation text "8 m, in 5 s" (8 m 5秒後) preparing for a right turn was ignored by 80 % of the probands. Yet, this floor display is the clearest and most direct one.

In Sample 3 the step sequence number and sequence overview could not easily be recognized at the first look, proper cognition needed a longer period of time. Furthermore, the sequence number and the landmarkings A and B were easily confused with one another. 19 m and the arrow direction were ignored by 19 probands.

In Sample 4 probands could not clearly determine if the "3 min" (3分鐘) shown in the dialog bubble was referring just to the current route segment or to the entire route length. The starting point symbols was misinterpreted as the current location mark, only two probands identified it correctly next to the A landmarking. The meaning of the dotted line (traveled route) and the solid line (route towards destination) as progress indicators on the lower part of the navigation, we not understood.

In Sample 5 the starting point was believed to be the current location, while orientation arrow was misinterpreted as forward indicator. Die dialog bubble "Exit 3" (3號出口) was the clearest destination marking, and received no incorrect answers.

**Table 5** Pros and cons of the design approaches

| | Destination instructions design | Floor display design | Graphic/text arrangement of navigation message | Multiple step navigation design |
|---|---|---|---|---|
| Sample 1 | | Worst | | (None) |
| Sample 2 | Worst | Best | Worst | (None) |
| Sample 3 | | | | Worst |
| Sample 4 | | (None) | | |
| Sample 5 | Best | | Best | |
| Sample 6 | | | | |
| Sample 7 | | (None) | | Best |

The design of Sample 6 placed the navigation message "Destination 1F Hall, South Exit" (目的地1F大廳南出口) to the top, while the navigation underneath still showed sequence problems, which necessitated more time to be recognized correctly.

In Sample 7, despite the "Turn right at A" (於A右轉) message being highlighted in black, it was not correctly interpreted by 60 % of the probands as a current location message. Neither could they recognize which floor they we currently on.

In another design approach multiple steps were combined within a single screen to give the probands an understanding of the entire route as a whole. Sample 3, Sample 4, Sample 6, and Sample 7 all utilized this multiple-step design. The results of the experiments allow us to divide probands into two categories. Category one are familiar with navigation systems and support the idea that navigation should be from top to bottom. Category 2 habitually feel navigation steps should be in the same order as the their progression line on the map, i.e., from bottom to top. Although most probands were able to learn the correct sequencing of steps by cross-referencing graphic and text, and referring to the destination mark, under time pressure in an evacuation situation the usage of multiple-step screen displays poses an extreme challenge and it seems rather questionable if victims would be able to stay calm enough to adjust. Two of the probands did not even realize at all, that they reading sequence from top to bottom was wrong.

Furthermore our experiments in Sample 2 and Sample 7 showed that probands could correctly finger-point at their current location, which was indicated by an arrow icon, even when the starting point was out of screen sight. This is quite contrary to Sample 4 and Sample 5 where probands more easily misinterpreted the starting point with the current location mark, and the positioning arrow with the movement marker.

The experiment made one particular discovery, out of all 20 probands two did not pay any attention to the text messages, but rather only looked at the maps. They use expressions like "turn left or right at the intersection", "I see a public square", "it seems next to a staircase" to describe the situation during the interview. The author concludes from such behavior that these probands blindly follow the person in front and might easily be misguided.

## 5 Conclusion

The purpose of this study was to develop a smart phone navigation interface design for users under psychological pressure to achieve highest efficiency in finding optimized evacuation routes. These empirical results deliver the "cognition speed", "answer accuracy index" and "decision-making process" score. The interface with the least amount of information load proved to be the one with the highest cognition speed, which in our experiment was Sample 5. Dividing the interface into two main parts (a) overview maps and (b) step-by-step evacuation instructions, showed to be helpful. The overview maps allow users to attain a complete look including current location and final destination. The step-by-step instructions provide for ad hoc action items, thereby minimizing confusion through unneeded information pieces. However, the location symbol in the “current location” feature of Sample 5 should be slightly revised indicating a segment endpoint, as e.g. in Sample 1, Sample 2 and Sample 6.

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# Study on Landmark Design of Wayfinding Map in Taipei Main Station

**Ken-Tzu Chang and Meng-Cong Zheng**

**Abstract** Taipei Main Station is the largest train station in Taiwan, putting it into the global top 25 of its kind. Improving wayfinding efficiency in the public space has become an ever more important task. For this study we optimized a 2.5D wayfinding map of the Taipei Rail Station. We analyzed the wayfinding behavior of travelers using the existing, conventional public map. Applying the "think-aloud" method we then recorded the probands' pathfinding process. The research found out that probands planning their cross-floor route mostly chose indoor landmarks to describe their way. When we compared these empirical data with the existing map, we found out that many landmark categories, their amount and even the actual visibility thereof did not correspond with the de facto situation. In adopting a true way-searcher's point of view, this research sets new design standards for future map layouts of the Taipei Rail Station's interior environment and indoor landmarks.

**Keywords** Wayfinding · Spatial cognitive · Map design · Landmark · Taipei main station

## 1 Introduction

The Taipei Main Station is a tri-rail joint station facility converging high-speed rail (Taiwan High Speed Rail—THSR), conventional train (Taiwan Railways Administration—TRA) and metropolitan subway (Mass Rapid Transit—MRT) services. This not only is making it Taiwan's most important traffic hub, but at the same time it is also the largest one in Taiwan when it comes to size and passenger numbers, moving more than 500,000 commuters on a daily basis, putting it into the

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global top 25 of its kind. Surrounded by a densely populated commercial, shopping and office area, the overall structure has 6 stories above ground and another four basement levels, with people moving in and out, and travelers or commuters transferring all the time in huge numbers. Coping with these huge amounts of people necessitates a well-planned overall design and management, and above all, a comprehensive as well as versatile guidance and signage system. The 2014 "Taiwan Railway passenger Intentions Survey Summary Report" by the Taiwan Railway Administration points out that "20 % of passengers are dissatisfied with the in-station guidance signage, they find them to be not sufficiently clear". This very vividly demonstrates the importance of an improved in-station guidance system to increase wayfinding efficiency. Furthermore, it underlines the importance to include landmarks into guidance maps as a means of spatial orientation, enabling passengers to easily find their bearings and direction of way.

Travelers in the Taipei Main Station trying to find their way around in the public space, expect accurate and intuitive map information. Therefore it is also important to point out, that the easier the map information elements are absorbable by travelers, the higher their wayfinding efficiency. This once more stresses the importance to develop a tailor-made wayfinding map for the TRA Taipei Main Station.

The design and presentation method of wayfinding maps also may vary greatly according to different environments and locations. In particular indoor spaces pose a special challenge to the map design, as people are easily getting lost when having to move horizontally and vertically at the same time. This increases complexity to a large degree [1]. Therefore, landmarks are one of the most commonly used means of orientation in wayfinding behavior, in May and others' [2] study on the impact different landmark types have during the wayfinding process, they conclude that landmarks are the most important clue for spatial orientation. Furthermore, it is the following features which proved most helpful: eye-catchiness, familiarity of objects, distinctness, and spatial proximity [2]. Eye-catchiness in this context does not merely pertain to its own characteristics as such, but rather how it sets itself apart as an obvious marker [3]. In addition, Denis and others' research has shown, that the first thing pathfinders mentioned to be looking for when trying to find orientation or look for the right way, are landmarks. Emphasizing clearly the importance they carry as reference information [4]. At the same time, from literature we can see, that everyone's way planning approach and strategy differs considerably according to their individual experience, spatial capabilities, situational information and personal backgrounds. On top of things, the amount of information and the way it is being displayed on the map itself, has a big impact on the willingness of people to make use of it. By the extent we increase the willingness to use such a map, we can also increase the overall ratio of how people in turn explore the public space. As to how far the current Taipei Taiwan Rail Station wayfinding map's design meets the public's and travelers' needs, and how further to improve their movement inside the space, is the decisive issue in the design of such a map.

# 2 Methods

## *2.1 Methods and Process*

For this study we started with a basic field survey in the Taipei Main Station, counting the amount of maps, their placement and frequency of use. The floor maps on the first floor with the highest usage frequency were selected as our map templates for later reference, analyzing the travelers' wayfinding behavior. We selected four locations within the station as our wayfinding targets for route planning and oral descriptions. In the end, the analysis allowed us to define map design parameters to improve wayfinding efficiency by enhancing landmark elements.

## *2.2 Pre-observation*

The Taipei Main Train Station is located right in the metropolitan heart of the city, surrounded by a lively shopping and commercial district, and serving as major traffic hub. For locals as well as travelers it is Taiwan's most important transportation transfer center and tourist destination, hence a perfect subject for our research. For this study we mainly focus on the first floor and first basement floor of the Taipei Main Station where most of the transfer movements between the Taiwan High Speed Rail, conventional train and subway takes place. At this stage of our field study we survey the types of maps, the total amount of maps, the distribution of the maps, their design layout and amount of people who utilize them, etc. In doing so, we gain a rational experimental basis. As actual at-site samples please refer to below photos, Figs. 1a, b and 2.


**Fig. 1** **a** Indoor space of Taipei Rail Station. **b** Part of the wayfinding maps on 1F

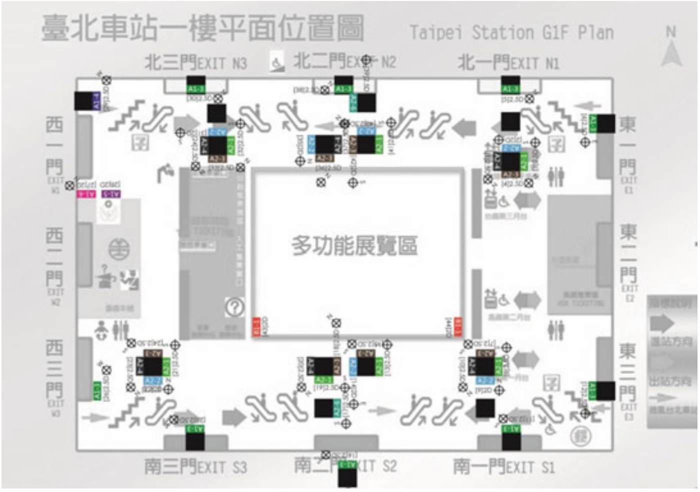


Fig. 2 Wayfinding maps' locations on Taipei Rail Station 1F plan

## 2.3 Indoor Wayfinding Experiments

In this wayfinding experiment we are using the floor maps on the first floor of the Taipei Main Station as template. Four indoor destinations are selected. Tasks are to locate them, plan they way towards them and an oral description thereof. We defined four different wayfinding spots including the first floor and the first basement floor with the main ticket counter on the ground floor being the center. Applying the "think-aloud" method we then recorded the probands' pathfinding process and codified it for comparability among the different subjects' cognitive orientation capabilities.

Starting point of the experiment.

Taipei Main Station, 1 floor, (column in front of gates South 3 and North 3).

Destination points of the experiment.

- Destination 1: Taipei Main Station, Eastern District underground parking, northeast side entrance (Floor B1).
- Destination 2: Chunghaw (Taiwan) Post at the side of Gates South 1 and East 3 (1st Floor).
- Destination 3: North Platform Exit of Taiwan Railway (Floor B1).
- Destination 4: Taiwan Railway Service Center (1st Floor) (Fig. 3).

Experimental Procedure

- Step 1: Before the experiment started, we gave a brief introduction of the experimental map.
- Step 2: We asked the proband to find the location of the respective task and locate it on the experimental map.

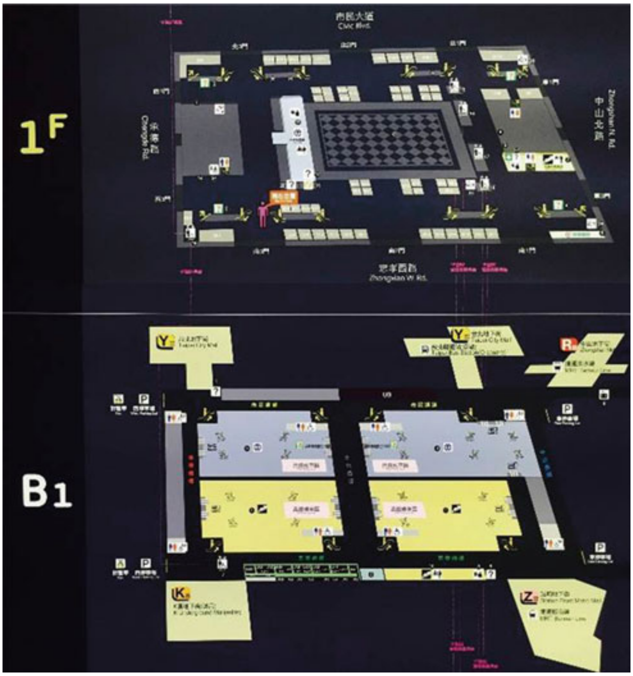


**Fig. 3** Wayfinding map of Taipei Rail Station on 1F and B1F

- Step 3: We asked the proband to determine the means of movement from the current position towards Destination 1, plan the route, and then collected the map again.
- Step 4: Now we asked the proband to commence from the starting point while there was no time restriction given during the wayfinding process. Overall a total of four destinations were to be found, starting from the column in front of gates South 3 and North 3 where instructions were given. Each phase began with the proband receiving their instructions and ended when the next target destination was reached. During the course of the experiment probands were not allowed to look for direction signs along the route, ask passers-by nor make use of the navigation devices at the access terminals. While the experiment was in progress, the proband was also asked questions concerning their behavior. When the proband made decisions or was in doubt, we enquired about his impressions.
- Step 5: After each phase had been finished, we asked the proband to outline the route he just took onto a blank map, and also point out the most recognizable and familiar landmarks.
- Step 6: In the end, we interviewed each proband and asked for their map improvement suggestions and the logic/principal according to which they had initially planned their route. Interview results were then systematically collected and arranged.

# 3 Results

This wayfinding experiment is divided into four parts: route planning description, "think-aloud" wayfinding process, drawing of a cognitive map, and a concluding interview. The results were separately recorded in order to analyze and compare differences among them.

In the first part of the "think-aloud" analysis we record the probands' descriptions during the route planning, classify them according to content and then codify them. Table 1 shows an overview of the 12 different terminology code conventions we applied. In Fig. 4 we find the total of route descriptions. Most frequently used

**Table 1** Wayfinding "think-aloud" terminology conventions code overview

| Code | Wayfinding description | Code | Wayfinding description |
|---|---|---|---|
| WD-1 | Current position (starting point verification) | WD-7 | Cardinal direction (use cardinal directions to describe a path) |
| WD-2 | Left/right-tendency (location determined by left/right handedness) | WD-8 | Destination (destination verification) |
| WD-3 | Left/right veering (left/right veering to describe a path) | WD-9 | Distance (use distance to describe a path) |
| WD-4 | Intersection (use the amount of intersections to describe a path) | WD-10 | Path patterns (use actual patterns along the route to describe a path) |
| WD-5 | Indoor landmarks (use indoor landmarks to describe a path) | WD-11 | Map directions (use the map orientation to determine a location) |
| WD-6 | Entrance name (use entrance names to describe a path) | WD-12 | Body turn (use the body orientation to describe a path) |

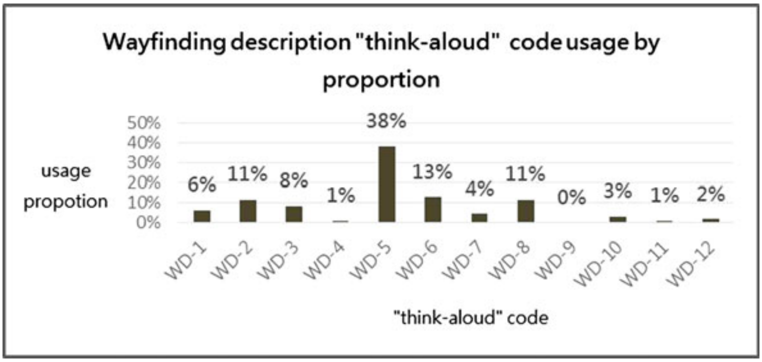


**Fig. 4** Wayfinding description "think-aloud" code usage by proportion

were Indoor landmarks (WD-5), entrance names (WD-6), left/right tendencies (WD-2) as well as destination (WD-8). The data from our four experimental destinations clearly show how landmarks on wayfinding maps effectively help probands to find their bearings and get a clear picture of their relative position. Station entrances also greatly contributed to the probands' effective orientation within the location. Furthermore the left and right intuition also played an important role, as well as the destination confirmation.

Results of the second part are based upon the records of the "think-aloud" content giving during the wayfinding process. As the experimental routes varied, usage of the respective description codes also show differences. By referring to Table 2 you can easily see that for Destinations 1 and 3 usage of description code is rather higher then for the two other destinations. In addition, using entrance names in the wayfinding description (WD-6) also tend to be more frequent. As for Destination 2, the overall description code usage shows the lowest number, with only three left/right veering (WD-3) instances. Destination 4 is dominated by Left/right-tendency (WD-2) and Indoor landmarks (WD-5) descriptions.

In the third part, probands drew a cognitive map, which included the pathway they just walked as well as indoor landmarks. In doing so, we were not only able to understand the level probands' cognitive comprehension of the pathway, but furthermore it allowed us to compare the initial planned route with the actual route taken in the field. After completion of each Destination experiment the originally planned route and the on-site path data combined with the individual cognitive maps were collected. Figure 5a shows each of the 14 probands' planned route before starting into the field. Figure 5b Displays the probands' accumulative road way within the field experiment. On the below illustrations you can easily see that the particular nature of this experiment included cross-floor orientation tasks including the 1st floor and first basement floors of the Taipei Main Station. When we compare the initially planned with the actually taken routes, we can see a greater discrepancy between the two of them on the 1st basement floor than on the 1st floor. Additionally, Destination 3 shows a noticeably higher deviation than the other three Destination pathways. When planning their routes, probands' explained that they felt the easier the path the better, and they prefer minimum of additional descriptions. This way they felt it was easier to avoid taking wrong directions during the walk, as too much information in a very limited amount of time would be easily be forgotten and lead to mistakes on the way.

The fourth part is the systematic analysis of the interviews, this part consists of two questions. The first question refers to the process of the experimental wayfinding and how to improve on the existing Taipei Main Station floor maps. The second question is targeting the specific issue of changing floors in order to reach a destination, and which method the probands applied to plan their routes. According to the interview contents we identified the following issues: 6 probands pointed out they could not intuitively find the location of cross-floor escalations, their numbers and markings were inconsistent and therefore caused confusion. Moreover, the up/down directions shown did not correspond with the actual movement directions. 5 probands pointed out that company/organization icons such

**Table 2** Wayfinding description "think-aloud" code usage by number

| | WD 1 | WD 2 | WD 3 | WD 4 | WD 5 | WD 6 | WD 7 | WD 8 | WD 9 | WD 10 | WD 11 | WD 12 | Total |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Destination 1 | 5 | 8 | 9 | 1 | 36 | 17 | 4 | 9 | 0 | 1 | 0 | 1 | 91 |
| Destination 2 | 5 | 8 | 3 | 0 | 23 | 8 | 6 | 11 | 0 | 5 | 3 | 3 | 75 |
| Destination 3 | 7 | 8 | 11 | 1 | 33 | 13 | 3 | 9 | 0 | 3 | 0 | 1 | 89 |
| Destination 4 | 5 | 15 | 6 | 1 | 39 | 6 | 2 | 10 | 0 | 2 | 0 | 1 | 87 |

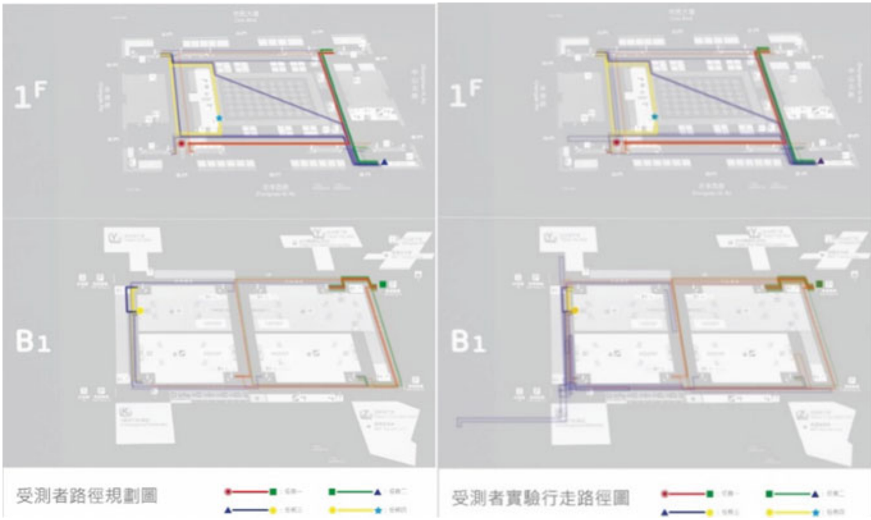


**Fig. 5** **a** Planned routes of probands. **b** Actual routes taken by probands

as post office, Railway, High Speed Rail should use different colors for better recognizability; at the same time they suggest to add Chinese and English short descriptions underneath the pictorials to make it easier for foreigners and travelers to understand the meaning, the fond size should be sufficiently big as well. 3 probands pointed out that the 1st Basement parking lot signage was very clear as it was directly printed onto a black background, different color coding for the parking space size information was advised. 2 probands mentioned the “question mark” used for indicating the Taiwan Rail Service center would easily be confused with similar pictograms of the Tourist Service Center or the Employment Center. 2 probands found out that the elevator markings on the map did not correspond with the actual on-site situation, locations where unclear. Furthermore this shortcoming was found on several occasions, a general overall review is proposed. Two probands pointed to the number markings of the pictographs on the maps being inconsistent, on the one hand side of the legend rounded frames were used while on the other side rectangle frames were applied. 2 probands mentioned a problem identifying escalators being within or outside the passenger area on the 1st basement floor, leading to a dead-end when the planned route meets reality, resulting in disorientation. 2 probands who were moving towards the Taiwan Railway platform north exit were under the impression that the black-marked walkway area would belong to the outside area already. Another 2 probands also pointed out that there was a Breeze shopping street on the 1st Basement floor which should be highlighted in the map marking.

The second problem complex is as follows: 9 probands tried to remain as much as possible on the first floor with their route planning, as they wanted to avoid the very complicated design of the 1st Basement Floor and feared they would easily loose directions and get lost. As the Taipei Main Station first floor is designed in a rectangular pattern, 8 probands used the entrance gates as orientation marks and defined their routes along these lines, additionally using 7–11 convenient stores as further help. 4 probands used the obvious checkerboard floor design in the main all of the 1st floor of the Main Station as an orientation landmark. 3 probands used cardinal directions for their wayfinding plannings. Three subjects said they tried to take the shortest path and reduce the number of turns, as well as avoiding overly-crowded areas. 2 probands mentioned they tried to adhere to walkways they had been familiar from previous experiences already, as they feel more at ease that way. 1 proband started the pathfinding planning by first identifying the bathrooms in all directions of the 1st Basement Floor.

# 4 Discussions

As we have seen in Part 1, the most commonly path descriptions used by the probands in the way planning process were indoor landmarks (WD-5), entrance names (WD-6), left/right tendencies (WD-2), and destination verification (WD-8). The experimental field results also reflected these records, probands made extensive use of indoor landmarks to avoid disorientation particularly when having to move between different floors. Secondly, since the 1st floor of the Taipei Main Station is foursquare with cardinal direction orientation of the side entrances, this considerable helped to identify one's destination and conduct the route planning in an easier fashion. As different people have different habits of finding their orientation, we found some probands took themselves as orientation center, thereby tending to use their own body to define left and right and thus determining their environment. Reconfirmation of the destination before their departure and repeated "loud thinking" also contributed to their memorization. Another result of our discussion clearly shows, that the addition of another turn and crossing between different floors (as in Destinations 1 and 3) also noticeably increases the total use of "think-loud" code when compared to the other two Destinations. This was of great help for the probands in order to reach their targets more smoothly, indicating that more wayfinding description is important in the planning stage. At the same time the cardinal direction orientation of entrances on the 1st floor proved particularly helpful with more complex routes. Probands could easily use entrance names to gain better orientation and find the correct escalators to move from one floor to another. As Destination 2. Represented the most simple path it's not surprising that this is also reflected the "think-loud" code amount. The wayfinding path of Destination 4. is of medium difficulty, and the survey results showed and increased use of left/right tendency (WD-2) as well as indoor landmarks (WD-5) for descripton. To arrive at their destinations the two most commonly used pathways used by the probands happened to be alongside the Train Station with indoor landmarks offering easy orientation, this allowed them to take advantage of left/right orientation (WD-2) and these indoor landmarks (WD-5) and accordingly use them comprehensively in their wayfinding descriptions. The third part shows that some probands displayed a larger than average deviation between planned and actually taken paths. From the "think-loud" records we can see, that this phenomenon mostly occurred after probands already found themselves disoriented or misjudged information, resulting in route changes. In the fourth and interview part of our study, we were able to collect valuable information how effectively to optimize wayfinding maps in regards to cross-floor escalators, their respective location signage, amounts and directions: clearly marked distance units, escalator and elevator numbers, unified character and number usage, color coded walkways as well as cardinal direction orientation of the entrance ticket terminals on the 1st basement floor, have been identified a measures to strongly help to move around inside the Taipei Main Station and gain easier orientation.

## 5 Conclusions

Our field study and research found out that when using the Taipei Main Station wayfinding maps, users most frequently tend to rely on indoor landmarks in order to find their destinations, and plan their routes towards them. When crossing floors the amount of indoor landmarks memorized increases accordingly. Secondly, travelers use the entrance gates to determine their directions and use their own left/right tendency as a help to find their way around within the Taipei Main Station. Reconfirmation of the desired destination before setting out does not only effectively improve clarity of the final target location but at the same time also improves awareness of one's own position within the traffic zone, making it easier to zero in on the destination during the pathfinding process. From the above research results, we arrive at the conclusion, that for future wayfinding map designs in the Taipei Main Station it is not sufficient to only provide accurate map information, but additional information elements should be added. These include, but are not restricted to, frequently used indoor landmarks and specific entrance gate names, which would allow for an easier and more intuitive wayfinding map design, this would significantly enhance overall wayfinding efficiency.

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# Design Entropy: A New Approach for Evaluating User Experience in User Interface Design

**Lei Wu, Juan Li and Tian Lei**

**Abstract** This paper reports on an experimental study on user interface in universal smart TV remote controls to measure the influence of information overload on user experience. Based on cognitive psychology and human factors, we proposed a design entropy model (DEM). DEM is measurement of the degree of information chaos in a user interface, which contains the "appearance design entropy (ADE)" and the "interaction design entropy (IDE)." To validate the model, we designed an experimental study, 82 college students participate in the experiment and the experiment material were three universal smart TV remote controls. The results showed that: (a) design entropy have a significant correlation with user experience; (b) high design entropy caused more disorder, thus significantly decreasing user experience; (c) low entropy design caused more order, thus significantly increasing user experience, which further verifies the validity of the DEM.

**Keywords** Information overload · User experience · User interface · Design entropy · Smart TV

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## 1 Introduction

In an information-based society, we constantly access with huge amounts of design information in user interfaces, which can cause information overload [1]. However, many of our everyday user interfaces have user experience problems, such as smart TV remote control, washing machine panels, ATM machines, and car operating panels, etc. [2]. Therefore, more research must be done to examine users' cognition and behavior confusion when interacting with those user interface designs. Product-user interface is the system of the information exchange between a user and a product, which consists of an internal form of information and the user's mental model. Additionally, interaction design defines the behavior of humans as related to the interface elements [3]. Usability refers to the ease of use and learnability of a product [4]. A user's experience involves a person's behaviors, attitudes, and emotions about using a given product, system or service [5], which focuses on the quality of the user's experience [6]. Consequently, a user-friendly interface allows users to efficiently accomplish given tasks.

Currently, a number of studies examine user's experiences, design methods and practices, such as those investigating cell phone designs [7], PDA and small screens mobile device designs [8], car operating panels [9], web pages [10]. In terms of research methods, user interface design research mainly focus on several aspects, such as layout factors [11], color design factors [12], form design factors [13], ergonomics factors [14] and interface aesthetic factors [15]. Many studies have also focused on visual complexity and its relationship with usability [16]. Researchers have investigated the organization and complexity of an interface or applied chaos theory to complexity. Schwamborn investigated different forms of visualization in texts [17]. Finally, Tsai explored emotions and visual information uncertainty with websites [18]. However, few researchers have measured user experience under information overload. Furthermore, research is lacking on the intersections of information overload and its relationship with user experience in universal smart TV remote controls.

To address these issues, this study forwards a methodology called "design entropy model" (DEM), which was used to evaluate the user experience of user interfaces. This method is derived from information entropy theory, and is generally used to describe the degree of disorder of an information system. Figure 1 displays the theoretical framework of this study.

## 2 Methods

### 2.1 Definitions

In this study, we applied the concept of information entropy to the design research field, which we called "design entropy" instead of "design of entropy" to

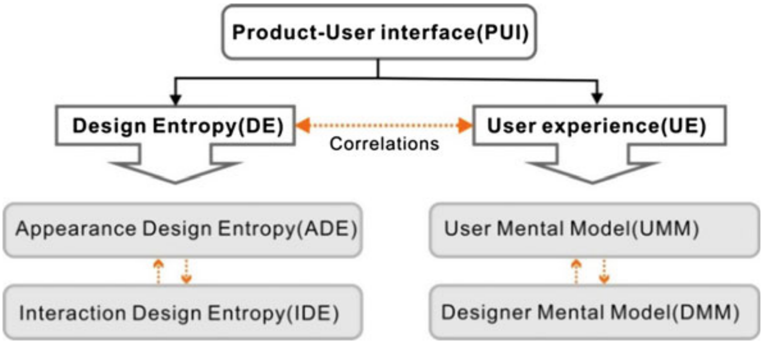



**Fig. 1** The theoretical framework of the research

differentiate it. Design entropy is defined as a description of the disorder found in design objects. Based on the information entropy theory, the design element corresponds to the information element; the design information corresponds to the information bit; and the designing process corresponds to the information coding, as shown in Table 1.

Consequently, we proposed the DEM (design entropy model) in product-user interface design. The design entropy model works as a function of the "appearance design entropy (ADE)" and "interaction design entropy (IDE)," as shown in Fig. 2.

**Table 1** The comparison of the design entropy and information entropy

| Feature | Design entropy | Information entropy |
|---|---|---|
| Element | Design element | Information element |
| Measure | Design information | Information bit |
| Rule | Design processing | Information coding |

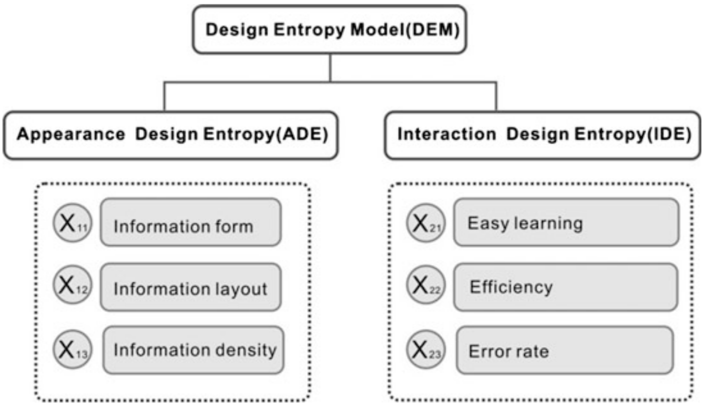



**Fig. 2** The structural of design entropy model

Based on the above analysis, the formula that constitutes a function of the design entropy could be expressed as (1):

$$\boldsymbol{DE}^{(Design\ Entropy)} = f\left\{\mathrm{U1}^{(\text{appearance design entropy})}, \mathrm{U2}^{(\text{Interaction design Entropy})}\right\} \quad (1)$$

## 2.2 Hypotheses

In order to confirm those hypotheses, we designed an experimental study. The independent variables in study were the two factors affecting the design entropy, which were the appearance design entropy (ADE) and the interaction design entropy (IDE). The dependent variable is total user experience (TUE).

The hypotheses of this study are as follows:

H1: High entropy design causes lower user experience score.
H2: Low entropy design causes higher user experience score.
H3: The appearance design entropy (ADE), interaction design entropy (IDE), and total user experience (TUE) have a correlation relationship.

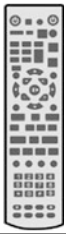
## 2.3 Participants

A total of 82 undergraduates, graduate students, and PhD candidates of HuaZhong University of Science and Technology were random selected to participate in this experiment. Of this group, there were 35 male and 47 female students, ages 18–45 (the mean = 26.15, SD = 3.27). Male subjects accounted for 42.7 % of the study, whereas female subjects comprised 57.3 %.

## 2.4 Material

TV remote controls have becoming one of the most confusing user interfaces in smart TV products. Most of people in this study thought that understanding and operating a TV remote control could be difficult, so the TV remote was a natural choice for the experimental study. After conducting six months of marketing research surveys and interviews with the target users, a total of 60 universal smart TV remote control samples were sorted out. Then, we invited 10 interaction design experts (Mean of age = 36.2, SD = 1.75) who have a master's or doctoral degree in industry design and human-computer interaction, with more than 8 years of industry experience to discuss the data from the initial consolidation of the 60 samples selected. After we conducted five discussions focused of the selection of

**Table 2** Three smart TV remoter prototype used in the experiments

| Name | Material A | Material B | Material C |
|---|---|---|---|
| |  |  |  |
| Cognitive complexity | Easy | Medium | Hard |
| Operation rules | Simple | Moderate | Complex |
| Number of elements | 20 | 43 | 69 |
| Design entropy | Low design entropy | Medium design entropy | High design entropy |

the materials. Three remoter prototype used in the experiments named the "high entropy type," the "medium entropy type," and the "low entropy type" for the experiment, as shown in Table 2.

## 2.5 Procedure

The experiment is a within-group design, so all participants were tested on the three levels of the experimental material. A repeated measure design was utilized to address the research purposes. Before the experiment began, participants were asked to read the introduction of the experiment requirements, and then sign the "Experimental Consent". Next, they read a short manual about the experiment material to insure they were able to understand and solve the given task. The test environment was a quiet laboratory without noise and interference, as shown in Fig. 3.

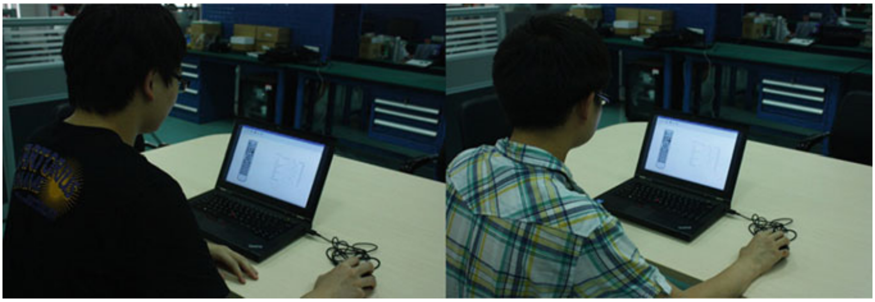


**Fig. 3** Participant in the experiment and the environment

**Table 3** The questionnaire of the experiment

| Number | Item | Number | Item |
|---|---|---|---|
| Q1 | Form | Q7 | Error rate |
| Q2 | Layout | Q8 | Interaction complexity |
| Q3 | Density | Q9 | Pleasure |
| Q4 | Appearance complexity | Q10 | Impressive |
| Q5 | Easy learning | Q11 | Reliable |
| Q6 | Efficiency | Q12 | Total user experience |

We designed three typical TV remoter prototypes in axure 6. The simulation was run on an IBM ThinkPad T430. Each participant was asked to complete three typical operations tasks (low, moderate, and high interaction design entropy: followed by adjusting the volume, selecting a channel and adjust the brightness) in each experiment material. We counterbalanced the three experiment material using a random method to compensate for learning effects. After the experiment, participants were immediately asked to complete a questionnaire. The questionnaires for the experiment included the 12 items shown in Table 3.

## 3 Results and Discussion

A one-way repeated measures ANOVA was used to examine the association between design entropy and user experience. Using IBM SPSS Statistics 19 analysis, the results were as follows.

### *3.1 Appearance Design Entropy*

In the Appearance design entropy (ADE) domain, the results showed that the lowest appearance design entropy is material A, the maximum appearance design entropy is material C, and material B is located in the middle level. The cronbach's alpha = 0.892**, displays the scale of the sub-factors has internal consistency. In the sub-factors of appearance design entropy, density is the most important factor ($r = 0.887^{**}$) that contributes to ADE, followed by the form factor ($r = 0.868^{**}$), the layout ($r = 0.511^{**}$), as shown in Fig. 4.

### *3.2 Interaction Design Entropy*

In the Interaction Design Entropy (IDE) domain, the result showed that the lowest interaction design entropy is material A, the maximum interaction design entropy is

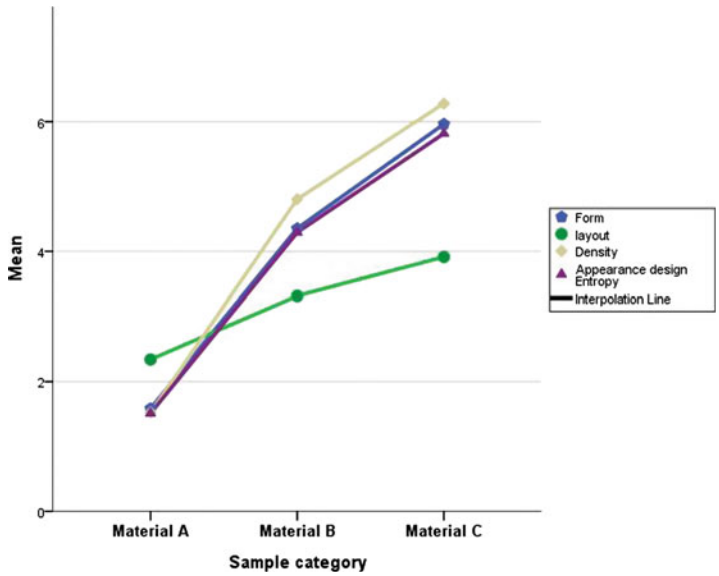



**Fig. 4** The relation between appearance design entropy and sub-factors

material C, material B is located in the middle level again. In the sub-factors of interaction design entropy, we found that material A had the maximum score for easy learning and efficiency and the lowest error rate. Material B had a medium score for easy learning and efficiency and a medium error rate. Finally, material C had a minimum score for easy learning and efficiency and the highest error rate, due to the fact that material C had the highest density and shape complexity. These issues caused the highest amount of user cognitive load during operation which then caused the user to spend more time consuming resources, thus resulting in higher operation error rate. Furthermore, we found that the error rate and interaction design entropy had no linear relationship between each other, but they have an interactive relationship. The cronbac"s alpha = 0.921**, displays the scale of the sub-factors has internal consistency. In the sub-factors of interaction design entropy, easy learning is the most important factor (r = -0.656**) that contributes to the IDE, followed by the efficiency factor (r = −0.620**), and the error rate factors, which had a relatively minimal influence (r = −0.593**), as shown in Fig. 5.

### *3.3 Total User Experience*

In the user experience dimension, material A had the highest score of users' experience, material B had a middle score for users' experience, and material C had the lowest score of users' experience. Regarding the sub-levels of the users'

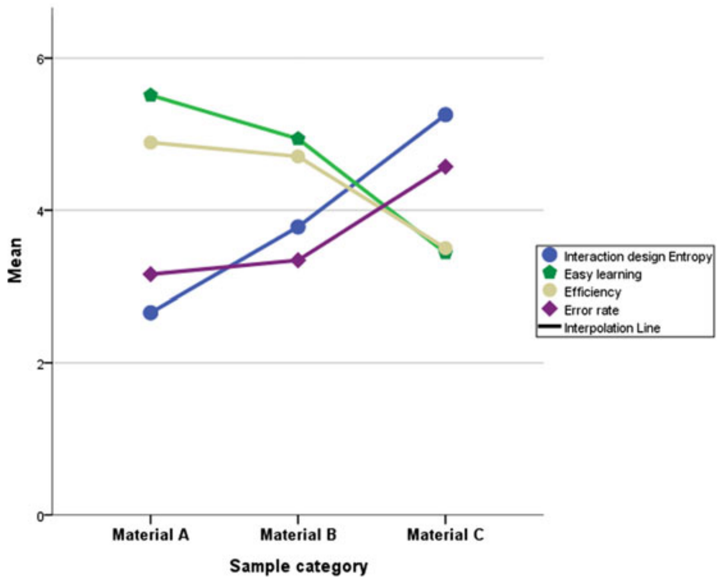



**Fig. 5** The relation with interaction design entropy and sub-factor

experiences, we found that users reported experiencing more pleasure when using material A, as opposed to materials B and C. We found that the impressive degree of differences between materials A, B, and C were affected by the familiar design and shape of material B, which was a more popular design. Thus, we speculated that a unique design would profoundly influence the degree of positive impact in a user's experience.

In terms of reliability, materials A and B scored much higher than material C, which may be caused by material C's high degree of density and information complexity, resulting in users' negative psychological experiences. In particular, we further speculated that minimalist forms and rational density will cause positive psychological effects, which can effectively improve users' experiences with product reliability. The cronbach's alpha = 0.905**, displays the scale of the sub-factors has internal consistency. In the sub-factors of user experience, pleasure was the most important factor (r = 0.758**) that contributed to the UE, followed by the reliable factor (r = 0.639**), and the impressive factor (r = 0.395**), as shown in Fig. 6.

From the statistical results, we can see that material A demonstrated the lowest interaction design entropy and appearance design entropy. On the other hand, Material C displayed the maximum interaction design entropy and appearance design entropy, and material B placed solidly in the middle. The total user experience score shows that the material A > material B > material C ($P < 0.05$). From the results, we can conclude that the interaction design entropy, appearance design entropy, and users' experiences have a negative correlation trend, which is to

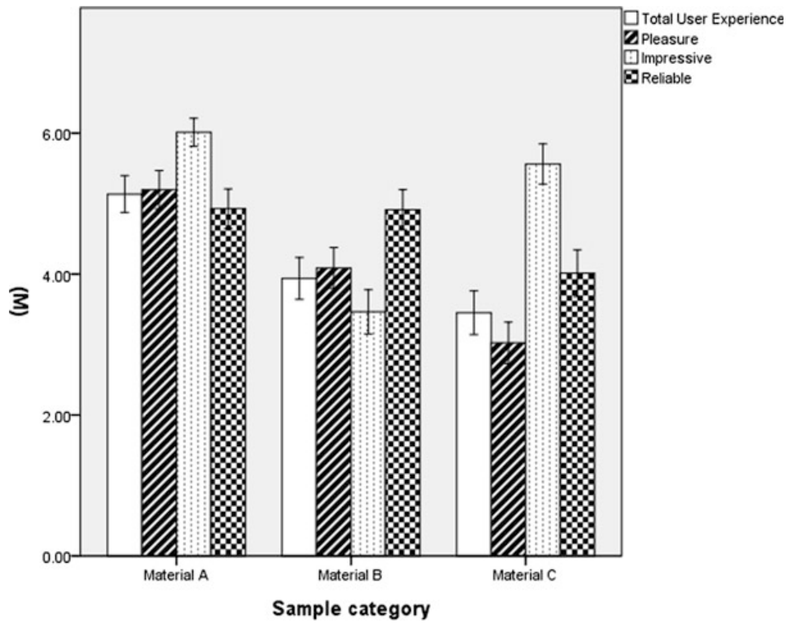



**Fig. 6** The relation with user experience and sub-factor

indicate that the higher the degree of interaction design entropy and appearance design entropy, the lower the user's experience score tended to be, and vice versa.

## *3.4 Correlation Analysis*

Using correlation analysis, we can see the interaction design entropy, appearance design entropy, and the users' experiences showed a significant correlation. When considering the interaction design entropy among the correlation coefficient, the user's experience is ($r = -0.619^{**}$); and the appearance design entropy and the user experience correlation coefficient is ($r = -0.572^{**}$), which indicates that the interaction design entropy (IDE) and the appearance design entropy (ADE) have a significance effect on the user's experience ($P < 0.05$). We used these two variables (interaction design entropy and appearance design entropy) to create a multiple regression equation in order to predict the total user experience. In general, this model is significant ($R^2 = 0.423$).

## 4 Conclusions

Fundamentally, this paper verifies that the design entropy has significant effects on user experience responses. The regression correlation between the design entropy and the user experience provide the basis of this research. Consequently, this study examines the design entropy method (DEM) to evaluate user experience on product-user interface. This experiment reveals that the design entropy method is an effective way to measure user experience. We investigated two main factors of design entropy in this research: the appearance design entropy and interaction design entropy. Through performing tasks on universal smart TV remote control, user performance was measured in a Likert scale questionnaire. The design entropy research model developed in this study can help designers gain a deeper understanding of the user experience in user interface design, which can inform better planning information elements and construction, thus enhancing the user's experience.

From the results, the main findings of this study are as follow: (a) high entropy designs caused more disorder, significantly increased the user's cognitive load, decreased the user's experience and satisfaction; (b) low entropy designs caused more order, can significantly reduce the user's cognitive load, and increase the user's experience and satisfaction; (c) the interaction design entropy and appearance design entropy have a significant correlation with the user experience.

In this study, we concluded that designers should make the product-user interface as simple as possible, while still providing the necessary level of functionality. Reducing the target information element that users complete to perform required operations and reconstructing the information architecture of the interaction domain. Information disorder or additional behaviors will increase the operating costs and the chaos of the information system, which will in turn increase user confusion. The goal of the user interface design is to make the user's interaction as simple as possible, in terms of accomplishing user goals. With this information in mind, a good design entails a minimal amount of design entropy, which is the most orderly design. The design is not just the way that the user interface looks; it should also create as simple a system as possible.

**Acknowledgments** This paper is financial supports by the Fundamental Research Funds for the Central Universities HUST: (2014QN017). This paper is also supported by the high-level international curriculum projects of HUST.

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# Analysis of the Detectability and Conspicuity of Fire Extinguishers Based on Placement Location in Low to Moderate Hazard Public Spaces

**Cesar Lorenzo G. Capistrano, Maria Jacinta K. Lagonera, Pattrick Louie B. Lim and Benette P. Custodio**

**Abstract** The fire extinguisher is the primary instrument used in fire accidents. The conspicuity of fire extinguishers are vital in emergency situations where there is a deterioration of perceptive and cognitive functions due to stress. Fire codes in the Philippines exist to ensure the accessibility of fire extinguishers which include display methods, height requirements, and visibility. The purpose of this study is to assess the detectability and conspicuity of fire extinguishers based on the current standards in the Philippines and improve fire extinguisher placement and its accompanying signs. Most commercial locations are low to moderate hazard areas. A response time experiment was used to determine the detection time of fire extinguishers in these locations under the current standards. Qualitative data was also collected to determine the perceived location. The results were used to improve the standards. The same tests were repeated to the proposed improvement in order to measure its effectiveness.

**Keywords** Human factors · Detectability · Conspicuity · Response time · Fire extinguishers

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# 1 Introduction

## 1.1 Statement of the Problem

The design and display methods of fire extinguishers in the Philippines is not specified in the Fire Code of the Philippines 2008 (RA 9514) [1]. Detectability and quick reaction times, especially in emergency situations becomes an issue despite the requirements provided on accessibility.

## 1.2 Significance of the Study

Fire extinguishers are the primary emergency instrument used in case of accidents related to fire. As such, the government requires establishments to have fire extinguishers available for use in various locations. However, aside from the availability of a fire extinguisher, is the detectability. The goal of the study is to assess the current standards in the design and placement of fire extinguishers, and propose revisions that will help make fire extinguishers easier to detect. By increasing conspicuity, the detection time is reduced.

## 1.3 Scope and Limitations

The study considered the location of fire extinguishers and accompanying signs relative to other objects and elements inside a room. The study focused on individual rooms which were classified as Low and Moderate Hazard areas. The proper distribution of fire extinguishers throughout a building was not considered. Beyond the scope of the study are the actual design and packaging of the fire extinguishers. All other types of fire extinguishers aside from the portable or hand-carried fire extinguisher are not included in this study. Also, the study did not consider the appropriate classification of fire extinguishers in the room; only the placement in the room was considered.

# 2 Methodology

The researchers used two main tests, the Still Picture Test, for determining expected placement and the Location Panorama Test, for determining detection time. The subjects of the Still Picture Test were shown images of different locations. They were asked to determine possible areas to place a fire extinguisher. In the Location Panorama Test, the subjects were tasked to find the fire extinguisher in the image.

The main measure is the detection time or the time it takes for a subject to locate the fire extinguisher.

Once all the tests were completed, the data was analyzed. The researchers identified the best area to place a fire extinguisher and accompanying signage based on the results of the tests. The Location Panorama Test was conducted again using the proposed optimal alternative. The response time was compared against that of the initial tests.

The main goal of the study is to determine the optimal display features for detecting the location of fire extinguishers. Three considerations were used in designing alternatives. The first consideration was the results of the tests. The qualitative comments of the subjects were used. The second consideration was the standards of other countries. The fire codes of other countries were benchmarked and adapted. The final consideration was concepts on ergonomics. Applicable concepts on detecting visual stimuli were considered.

The tests were done on an initial sample. The appropriate sample size was then computed using the mean and standard deviation of the initial experiment with a deviation tolerance of 10 % and level of significance of 5 %.

$$n = \left(\frac{s \cdot t_{0.05,n'-1}}{k \cdot xbar}\right)^2 \tag{1}$$

$s$ standard deviation
$t$ t-table value
$k$ deviation tolerance
$xbar$ mean of sample

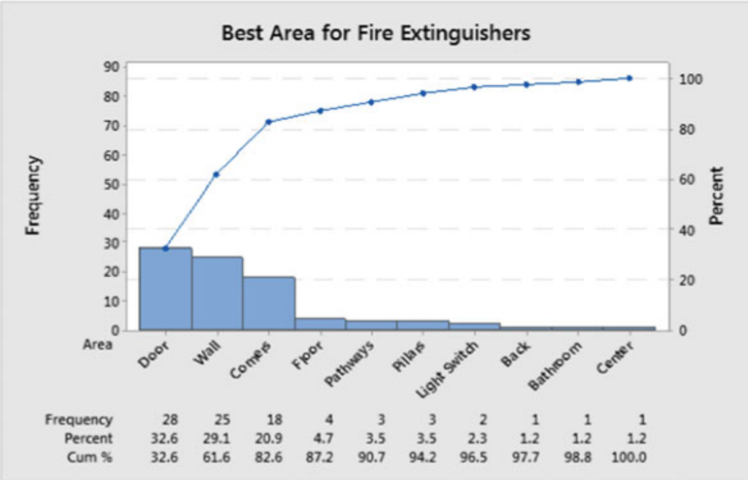
# 3 Results and Discussion

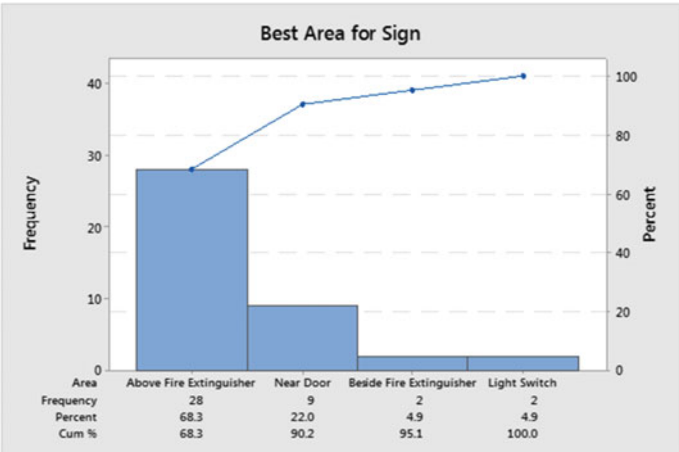
## 3.1 Initial Tests

Initial Location Panorama Test was used to set a standard for detection time under set conditions. The test used 2 different locations. The results of the test are summarized in the table below.

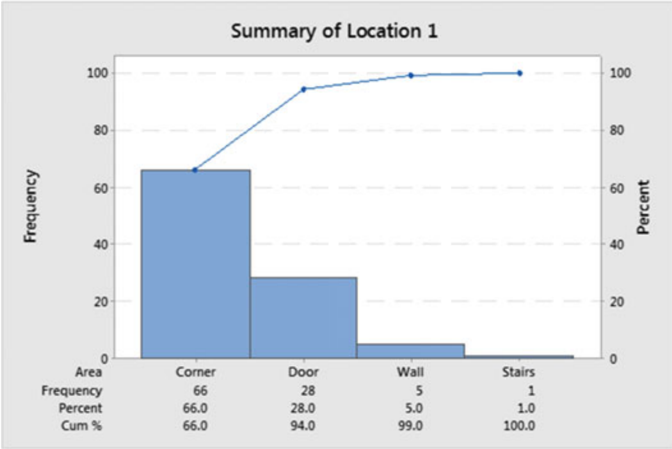
| | Classroom | Library |
|---|---|---|
| 5 % Trimmed mean (in s) | 2.34 | 2.43 |
| Standard deviation (in s) | 0.946307 | 1.025386 |
| Sample size | 41 | 41 |
| Square root of sample size | 6.403124 | 6.403124 |
| Tolerance (t = 2.021) | 12.78143 % | 13.3145 % |

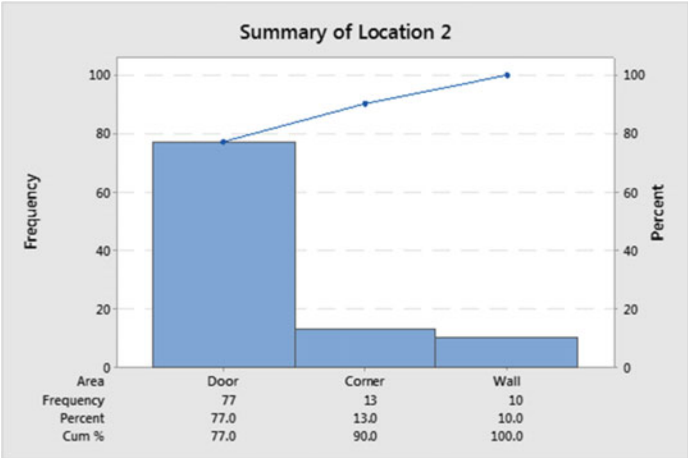
The test subjects were also asked to determine their expected location for fire extinguishers, and where a sign should be placed to make fire extinguishers easier to detect based on the given test locations. The results, summarized in the Pareto Charts below, suggests that fire extinguishers are generally perceived to be located near doors, corners, and walls, while signs should be located directly above fire extinguishers.

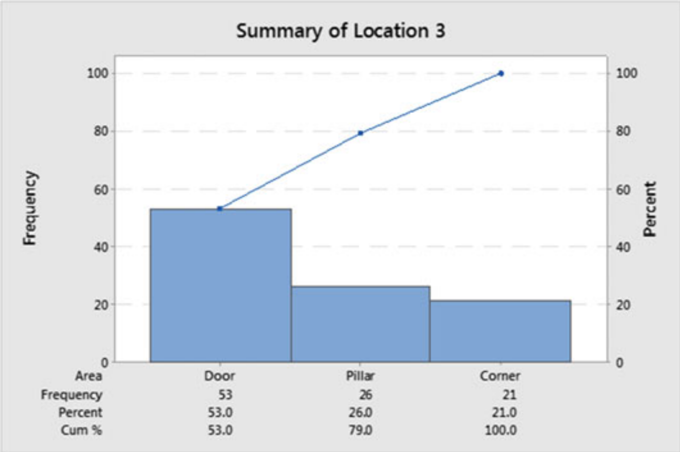


Using the Still Picture Test, another set of subjects were asked to identify which among the prescribed landmarks in each of 3 different locations is the best place for a fire extinguisher. The summary of the responses is summarized in the Pareto Charts below:






The results of the test show that fire extinguishers are best placed near doors and corners on all 3 locations. A large percentage of the respondents chose for it to be placed near doors since doors are always easily visible and its location is easier to recall as each individual inside the room should have already passed through it at least once. The corner was also selected because it was easily visible in Location 1, and because it was perceived to be the most accessible landmark in the room.

## 3.2 Secondary Tests

The Location Panorama Test was repeated on a different sample. The same locations were used but some elements in the picture were changed to consider the results of the initial test. A sign designed according to specifications benchmarked from international fire codes was placed at an eye-level directly above the fire extinguisher. The placement of the fire extinguisher was retained since it was already placed at an appropriate location suggested by initial test. The results of the test are as follows:

| | Classroom | Library |
|---|---|---|
| 5 % Trimmed mean (in s) | 1.73 | 1.98 |
| Standard deviation (in s) | 0.609044 | 0.653465 |
| Sample size | 54 | 54 |
| Square root of sample size | 7.348469 | 7.348469 |
| Tolerance (t = 2.00735) | 9.626038 % | 9.002738 % |

The data obtained from the Location Panorama Tests were subject to a two sample t-test to determine if there was a significant difference between the means of the initial test ($\mu_1$) and secondary test ($\mu_2$). This was done for each of the 2 locations used in the initial and secondary test.

The null hypothesis of the t-test states that the mean detection times for the two samples are equal. The *P*-values in the table below are computed from the initial and secondary tests for each location.

| Location 1: classroom | | | | | |
|---|---|---|---|---|---|
| | N | Mean | Standard deviation | SE mean | *P*-Value |
| Initial | 41 | 2.337 | 0.946 | 0.15 | 0.000 |
| Optimal | 54 | 1.728 | 0.609 | 0.083 | |

| Location 2: library | | | | | |
|---|---|---|---|---|---|
| | N | Mean | Standard deviation | SE mean | *P*-Value |
| Initial | 41 | 2.43 | 1.03 | 0.16 | 0.009 |
| Optimal | 54 | 1.983 | 0.653 | 0.89 | |

With *P*-values 0.00 and 0.01 respectively, the null hypothesis is rejected at a alpha of 5 % for both Location 1 and Location 2. This implies that mean detection time for the Initial Location Panorama Test is significantly greater than that of the Alternative Location Panorama Test.

## 3.3 Benchmarking of Other Fire Codes

Based on Philippine standards, fire extinguishers should be located where they are readily accessible in the event of a fire. It also states that fire extinguishers shall not be obstructed or obscured from view, except in large rooms. In certain locations where visual obstruction cannot be completely avoided, arrows, lights, signs, or coding of the wall are acceptable means of identifying its location. According to Section 10.2.6.5 of this code, portable fire extinguishers shall be provided in all institutional occupancies [1]. Similarly, the Occupational Safety and Health Administration (OSHA) in the 1910.157 standard states that the employer shall provide portable fire extinguishers and shall mount, locate and identify them so that they are readily accessible to employees without subjecting the employees to possible injury [2].

The Australian Standards state that fire point location signs must have white text and symbols on a red background located no less than 2 m above the ground. The extinguisher and sign must also be visible at a 20 m radius [3]. The UCL Fire Safety Technical Guide also recommends using red backboards with appropriate dimensions [4]. This may be added as an optional requirement in locations which are particularly cluttered or obstructed. The Philippine Fire Code, in comparison with international standards, can be improved by installing accompanying signs above the fire extinguisher at eye level.

### *3.4 Concepts on Visual Stimuli Detection*

Several human factors are considered when assessing the perceptibility and conspicuity of fire extinguishers. First are the visual capabilities of an individual such as fixation, accommodation, and color perception [5]. Next are design qualities which vary between products made by different manufacturers. These qualities include the size, placement and illumination of fire extinguishers and accompanying signs. Last are environmental factors or the stimuli pre-empted to the individual. Examples of these are stimuli complexity, stress, warnings, and distractions [6–8].

From the samples observed, it was found that public commercial establishments used in the study do not consider all of these factors. Although most fire extinguishers observed are designed for conspicuity, considerations on visual capabilities and environmental factors are usually overlooked. A common observation is how fire extinguishers are not hung or suspended at a noticeable height, and how the accompanying signboards are not designed to be easily detectable. If it is at the same height as the eye level of an individual, delay caused by adjustments made by the eye for proper visual fixation and accommodation will be reduced.

With regards to color, red should be used because it is easily distinguishable from the environment and it implies urgency [9].

## 4 Areas for Further Studies

There are still numerous concepts which can be explored to improve the detectability of fire extinguishers. The distribution of fire extinguishers throughout an area should be considered if a larger scope is to be studied. Other display materials can be explored and tested to determine which best accompanies a fire extinguisher. The design of the signs used for fire extinguishers can also be studied. Finally, high hazard areas, like kitchens and workshops, can also be included in studies which focus on the safety of workers.

Accessibility is another issue which should be explored. The weight and size of fire extinguishers relative to the capabilities of the population could be checked. The hanger or cabinet used to mount the fire extinguisher can also be explored.

Finally, there is the matter of usability. Not everyone knows how to use a fire extinguisher. The relation of the fire extinguisher's conceptual model and the user's mental model can be studied to address this.

## 5 Conclusion

A significant improvement in detection time was observed when the improvements were implemented. It is therefore advised to adapt the findings of the study to improve the detectability of fire extinguishers. These provisions should be added to the existing fire code and implementation of the rules should also be prioritized.

The Fire Code of the Philippines only states that fire extinguishers should be placed along normal paths of travel. It is recommended to add a clause requiring fire extinguishers to be placed either at doorways into the rooms or at the corners, whichever is available. Fire extinguishers are proposed to be suspended at a height that intersects the line of sight of an average individual. If it is not possible to hang the fire extinguisher, the researchers propose that red signboards signifying the presence of the fire extinguisher be placed above it at a height that also considers an average individual's eye level. Along with this, a requirement to place signs, regardless of the placement of the fire extinguisher, is recommended.

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# Information Searches by Vehicle Engineers in Engineering Design Development

**Shuai Zhang and Aylmer Johnson**

**Abstract** The development of design support requires a clear understanding of the situations that need to be improved. A literature review has identified that only few studies have observed the way in which design practitioners work, in an industrial environment; and since those few studies on this topic were all conducted 10 or 20 years ago, their findings may no longer reflect current practice. This study investigates the information needs of designers, and the different approaches and resources that they currently adopt to fulfil these needs. The research was performed by interviewing eight engineering designers. The analysis of the interview transcripts leads to the main findings of this research.

**Keywords** Information searches · Human behaviour · Design development

## 1 Introduction

Rapidly evolving IT technologies have introduced many computer-aided tools and provided various forms of knowledge resources for engineering design. Even though previous studies in engineering knowledge management [1, 2] have attempted to understand designers' information handling behaviours, these studies are not generalizable for the situations to be investigated in this research. There is no literature to provide an understanding of designers' current information needs, or the way in which they deal with these needs in practice.

The proposed research intends to complement the existing research in the area of designers' knowledge and information needs. It aims to extend previous research in two directions: (1) by exploring how designers handle their current information needs in design tasks, and (2) by contrasting their information requests with the

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retrieval capabilities of available data sources in practice. Even though previous studies have addressed the access of information in general [3] or for design community in particular [4], the existing research is bounded by time and context.

The hypothesis this research explores is that 'we don't know how designers currently meet their information requirements.' To address these gaps in our knowledge, the proposed study focuses on how designers handle their information needs during design development. More specifically, this can be further divided into the following four research questions:

(1) What information do designers need to generate design ideas?
(2) What information do designers need to assess their design ideas?
(3) What knowledge resources do designers have?
(4) How do designers find their required information?

## 2 Literature Review

There exists a lack of understanding of how designers currently fulfil their information needs in design practice. Even though there exist studies [4, 5] seeking to understand engineering designers' information needs, which identified that formal knowledge sources were hardly consulted, the majority of these were conducted years ago in British aerospace industry and might not capture all the information requirements of designers, especially in the context of the information sources which are now available. They also fail to capture the impact that the widespread availability of computer-based information retrieval tools may have had on the ways designers fulfil their information needs.

It has been established that the reuse of design knowledge is beneficial to designers and companies. These benefits have been identified by Busby [6], and can be summarized as (1) reducing efforts in rework or duplication; (2) reducing errors and uncertainty; (3) maximizing product familiarity; (4) helping customers maintain consistency in using and maintaining products; (5) generating improved design outputs.

Approaches and systems have been developed to promote the reuse of design knowledge, including process-based support [7], case-based reasoning [8], indexing systems [9] and retrieval systems [10]. These studies mainly focus on developing prototypes of systems to better assist the handling of design information and knowledge. These studies are mostly motivated by a practical problem reported from industry, and focus on addressing one particular kind of issue. There is a lack of a 'big picture' illustrating designers' information needs. Besides, as there is very limited implementation of these systems in industries, few databases have been generated for these systems. Research in investigating the interaction between designers and such systems is rarely conducted, except for few initial attempts in examining a knowledge-based system/environment [11].

Research into the information-searching behaviour of designers has been conducted to investigate information reuse from different angles. The usage of knowledge and information identified by researchers varies significantly, e.g. Pahl and Beitz [12] estimate that 80 % of new designs are generated from the reuse of previous designs, while Ettlie and Kubarek [13] identify a much lower number of 28 %. Another study by Al-Ashaab et al. [14] finds that—'refresh' products, i.e. projects with minor changes, constitute 60 % of the total number of projects. These studies explore the usage of previous information and knowledge. However, they do not involve identifying the types of information that designers search for, or how designers fulfil their information needs. Further work needs to be done in this area to provide a comprehensive understanding of designers' information needs.

Researchers in engineering design have attempted to study the use of knowledge and information in the process of design/product development. Efforts have been made by researchers to understand the nature of knowledge and information needs [15, 16] and the reuse of information and experiences [2, 4]. These studies focus on the handling of a detailed level of knowledge and information, such as questions and conjectures—for instance Ahmed [17] identified eleven topic areas from the analysis of discourses by eleven designers. This research area mainly aims to identify what knowledge or information generated in the design process should be captured. However, the information that should be captured may not be the information that designers use in practice because (1) it may not be the information needed most frequently or (2) there is no efficient retrieval method or (3) the capture of information and knowledge consumes time and does not benefit the originating designers directly, so designers are reluctant to capture the information properly, leading to the lack of resources for subsequent reuse.

As modern manufacturing companies start to shift their business models from simply providing artefacts to delivering products and ongoing services such as maintenance, the concept of product life cycle performance has attracted attention from research and industry communities to better understand the in-service performance of products. Research exploring the information needs of designers from in-service experience has been carried out by Jagtap and Johnson [18]. They interviewed three designers and asked these designers to comment on a list of potential questions that they might wish to ask in their work. Even though this research identified some most important issues designers wish to know, there is almost certainly still something out there that is unidentified—we probably do not know everything that designers wish to ask, and need to ask. This is possibly caused by the difficulties in finding out the answers or the lack of relevant data to answer. A survey by Heisig [19] explores the knowledge and information needs involving both designers and other roles such as managers, consultants and analysts. It aims to explore the plurality of knowledge and information needs of the main stages in the product life cycle with an emphasis on future engineering tasks. But there is still a lack of understanding about the needs of designers who deal with design tasks.

# 3 Interview Study

In this exploratory study, eight participants with different levels of experience from vehicle industry were interviewed. The topics discussed included their information needs in engineering design and how they handle their information needs. The participants were all involved in a technological part or module of a vehicle.

Semi-structured interviews were used in this exploratory research. Eight interviews were conducted with designers in the Chinese automotive industry between June 2015 and August 2015. Because of the geographical distance, the various locations of the different participants and the limited time for this research project, these interviews were conducted by phone. The length of the interviews ranged from 33 to 48 min, with a mean time of 38 min. There is no strictly formed list of questions for semi-structured interviews. The content of the interviews changed as new themes were identified during the interview process, which refined the research direction. The loose structure of interviews can be divided into three steps.

(a) Participants were asked to introduce their background/experience and job role in the company.
(b) Participants were asked to describe how they generate and assess design ideas and what information is required to complete design tasks.
(c) Participants were asked to explain what approaches they use to search for the information they require.

The interviews were recorded, and the recordings were transcribed immediately after the interview with the memos to transcripts for extra information such as valuable thoughts or points generated during the interview. The researcher also took notes when conducting the interview to increase engagement, and in case of problems with the audio recording.

# 4 Main Findings

## *4.1 Participants' Information Needs*

We identified three broad types of information searches: (i) those related to deriving design requirements from customers' needs, (ii) those related to existing solutions, and (iii) those related to design criteria and regulations.

(i) Deriving design requirements from customers' needs

From the interviews, we identify two distinct scenarios within which designers derive design requirements from customers' needs: (1) designers are given a general description that expresses customers' needs; (2) designers are given a set of technical requirements, such as parameters or characteristics of components, which express the customers' needs. In the former scenario, designers need to perform the additional step of translating the general description into technical requirements for design development.

> Generally, we need to focus on customers' needs. We should fulfil the technical requirements derived from the oral words expressing customers' needs…. In general, parameters provided by the customer are required. I need their expectations of the product, like what the product can achieve. I also need information about its working environment—Interview 05.

The parameters or characteristics expressing customers' needs can be used as the starting point for searching existing designs.

> We need the parameters and characteristics of vehicles and braking systems at the beginning. Based on these parameters, we search the previous vehicles with similar parameters—Interview 03.

(ii) Existing designs as a source of information

All the participants reported that, when given a design task, they would begin by searching for cases that they saw as being "similar". Through studying similar designs, designers sought to reuse existing designs or derive inspiration from the existing solutions.

> I need design solutions of similar cases, like files containing design details. I also need 'lesson learned' in previous projects and test reports… Apart from technical reports, you may also need graphs, tests and software—Interview 01.

> Existing design solutions can be reference for new design tasks. I usually look through the whole plan to find out the thoughts and logic in the design. There are important features such as the arrangement and assembly of components and parts which we expect remain the same, and the feedback from customers which we need to keep in mind to avoid similar problems. We try to avoid repeating the same failures in the new product—Interview 05.

While "similarity" between the current task and the existing solution would depend on the perspective taken by the designer, it was often articulated simply in terms of shared characteristics and parameters.

> When we develop design solutions, we start with searching similar cases in the company database. As our work involves structural design that has special requirements in the manufacturing of cavity and craftwork, I need to measure the same characteristics of similar cases and apply them in the current task for reference. After we work out the design plan, we also need to deal with the structural parameters—Interview 07.

The information sought often spanned different levels of detail and modes of representation.

> As long as I am given the task, I will ask for their documents such as drawings, function specification, previous design solutions, changes in the design solutions and the reasons for these changes—Interview 02.

Designers also looked to existing solutions when considering downstream activities such as the feasibility of manufacturing and production process in terms of budget and time.

> The first issue is the ability in production of our factories. Our design solution should be feasible and achievable using existing technologies. We need to check whether our factories can produce what we designed. If it is not feasible, we may have to talk to our customers to explain this issue, or check if any other companies can do it. There are lots of situations to deal with. The second issue is about controlling the cost. Our suppliers provide some of the components. Our own factories and workshops produce other components. In this case, we need to know our own production ability and decide whether to buy the components from other companies or to produce them by ourselves. If we plan to make the components by ourselves, we also need to know if it is easy to be manufactured and assembled—Interview 06.

(iii) Design criteria and regulations

As well as designing to meet users' needs, designers need to consider other constraints, such as those related to safety rules or industrial regulations. For example, designers need to check the legal requirements for safety when developing and evaluating design solutions.

> …Then I need to consider the safety requirements based on the national regulations for the local market or other international regulations for overseas markets. In general, the first issue to consider is the requirement; the second one is the regulation—Interview 02.

## 4.2 Searching Methods and Knowledge Resources

From the interviews, the methods that designers use to search for information can broadly be divided into two types: (i) consulting others and (ii) independent retrieval in company database with the help of information tools.

(i) Consulting

All interview participants acknowledged that consulting with others is a way of searching for information in their work. People consulted by designers include other designers, supervisors, suppliers and staff in other departments. Usually, a designer consults when he cannot find what he is looking for, due to the fact that (1) the required information is not stored in the database; and (2) existing retrieval methods are not efficient.

> It would be good if I can get what I look for. There are other approaches if I cannot find it in database. I can discuss this issue with experienced designers or colleagues—Interview 05.

Designers also need to consult when they are not sure what information to search for. Two scenarios are particularly common: (1) designers don't know the right question to ask or which direction they are supposed to work on; and (2) designers have some knowledge of the topic but cannot formulate their information requests.

> A wrong question would lead to working on a wrong direction. You will realize that it is not right at a certain point later, which wastes time. In this case, you may want to discuss the problem with a colleague to find the way out—Interview 05.

From the interviews, we also found that designers try to acquire background knowledge related to the topic before consulting with others, and attempt to learn from existing information sources to build an initial understanding of the design problems they are working on.

> There is a process. Firstly, you need to build your own understanding of the issue. Then you will form a question that expresses what you want. You can't ask other people before you get a basic idea of it. People would be annoyed. Besides, it is not efficient—Interview 04.

After developing their design solutions, designers typically submit their designs to other designers and supervisors for peer-review and approval. This 'comment-improvement' process can be regarded as a necessary consulting process in design development.

> In some cases, a design task cannot be completed by only one designer independently. It requires a team with various knowledge and experience to work together. For example, if I have a preliminary idea of design solution, I need to test and verify it by modelling or simulation. Then I will show the solution to an expert or a director for approval. Usually, supervisors in higher positions have more experience and are able to give us some advice in how to improve it. We can then work out the details based on their feedback—Interview 07.

How frequently designers consult varied considerably, most likely because of their different levels of experience. Interviewee 02, who has the least experience out of all the participants and works on new business in the company reported consulting with colleagues on roughly 50 % of the occasions when he was searching for information. By contrast, interviewee 07 reported consulting on only 10 % of the occasions when he was seeking information, which is significantly lower.

> At the beginning of design, there are a lot of issues/topics unknown for me. But *others may have already got some background knowledge. The processes of acquiring the background knowledge and understanding these topics are not easy… If it is a normal design task, I usually work out the questions one by one and find out the essence by analysis… The occasions of consulting others v.s. the independent search are 50/50*—Interview 02.

> Around 10% of the occasions when I need information, I will consult an expert in my daily work. As vehicle development does not require lots of innovation in design, we can find existing solutions or relevant information for reference to deal with about 95% of new design problems. We only need to develop new design ideas for the remaining 5% of design issues. So in general, we usually do not need to consult other colleagues—Interview 07

(ii) Independent retrieval

The designers interviewed reported that having design criteria and product components labelled in a systematic way made it easier for them to find the information required.

> In our company, each component is labelled with an ID. I can describe you our way of information retrieval. For example, if I need to see a previous design for side door, I can identify the IDs of similar component. The component ID is consisted of 9 numbers. The first three as a group indicate the vehicle model. The three in the middle represent the parts. The last three numbers refer to the component. The same components in different vehicles have the same last six numbers in their IDs. So I can easily find out the information of the same components in other vehicle models… In our database, we define the standards and

criteria. For example, we give a unique ID for the criterion of crash-resistance and put it in our database. When we need it, we can search by the ID number—Interview 07.

If that failed, they would use a separate database with 3D modelling data, which they would search manually.

Even if we cannot find what we want by component IDs, we have another database containing the 3D data of all vehicles. We can identify the component and the relevant information we need in 3D models—Interview 07.

As well as 3D modelling data, there are other forms of information that designers need to access, which are difficult to search for. Often these require having to read from the top to the bottom of hierarchies.

The information in database is categorized based on which systems it belongs to. For me, I go for the braking system directly and then look into part and component… You can search the name of part rather than the names and information of the components. You have to read through all the components in the part or unit—Interview 03.

Seven designers interviewed reported using keyword-based search engines when looking for information in the database.

All the guidelines are stored in company server. You can search by keywords—Interview 08.

## 5 Discussion and Conclusions

In contrast to the literature of empirical studies [4, 5], the interviews presented in this report offer new insights in designers' preference in the approaches of searching for information. The interview participants tend to search information more independently and consult colleagues significantly less than the scenarios observed in previous empirical studies. This contradiction may be caused by several factors, e.g. different industries, different cultures in the companies/countries, different available design tools and information resources etc. The contrast suggests that designers in this study generally prefer to use other information resources rather than consulting with colleagues. If so, this would indicate that the future research in this area ought to focus on how designers currently use information sources and retrieval methods, with a view to developing enhanced methods for information retrieval if it is found that the existing methods are failing to satisfy designers' needs.

Although this qualitative study provides findings in contrast to the existing studies, some of the themes that emerged from interview analysis fit with those studies. For example, participants reported the difficulties in exploring knowledge just after being given an unfamiliar design task, which corresponds well with Acker [20] and Blessing [21] which identified that searching information without precisely knowing what is required is difficult. Participants also indicated that they need assistance in formulating the right questions which explicitly and correctly express their information queries, which corresponds well with the findings of Ahmed [9]. The consequence of asking the wrong question, as reported by designers, adds context to the studies of retrieval performance [22, 23], which mainly focused on the evaluation of keyword and hierarchy indexing schemes.

The existing keyword retrieval and hierarchy indexing schemes have poor recall, although they are quite precise. Issues identified from the recent interviews reveal designers' wishes to improve the situation, supporting the findings of previous studies [4, 21, 22]. For example, Charlton's [22] statement says 'the natural tendency of classifications is to separate information, eliminating any similarity between different elements.' The information retrieval experience of designers supports this finding: a knowledge base, which uses a single index or hierarchy, is not able to provide the full range of suggestions that are related to designers' inquires. When comparing a query against an index, the piece of information is only matched in one classification, based on some of its attributes (for instance, a component is grouped in a classification that consists of all the components that belong to a part/unit). As such, the other attributes of the piece of query will neither be detected in that classification and will nor be compared with in other classifications (for instance, the component grouped in the classification of components for a specific part/unit may not be grouped in the classification of the components from different part/units that can perform a certain function). As a result, designers cannot explore knowledge or get reminded of the issues which are not considered or related.

As this study identified different findings from those reported in the existing literature, further research is necessary to explore this contradiction. Better or more detailed information needs to be acquired to investigate the current situation in design. This probably needs to be done by direct observation, which has a higher cost in time and effort than telephone interviews.

This research project fills a gap in the literature between the previous understanding of designers' information handling behaviours and current design practice. The exploratory research identified that the methods used to search for information may have changed. The finding of this research indicates potential directions for further research: building a more detailed understanding of designers' current practice, specifically designers' queries, methods of searches and information sources.

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# Ergonomics and Information Design: Design, Standardization and Uniformization of Graphical Symbols for Public Information

**João Neves, Fernando Moreira da Silva, Daniel Raposo and José Silva**

**Abstract** The present research addresses the issue of public information and try to achieve the standardization of sign systems, thereby contributing to the uniformity, legibility, understanding and perception of quality of guidance systems, by normalizing the existing signaling, the development of new methodologies applied to the design of symbols and even the application of a tool to assist the design of signs systems specific for public information. This study contributes to a broader understanding of the systems of signs and the interrelation of its components. It seems crucial to this research, which aims at obtaining a detailed study of signs systems for public information, a careful analysis of all aspects related to three areas: The sign and its meaning; The system or how signs are organized; The Culture or users to whom the signs are developed.

**Keywords** Information design · Orientation systems · Signage · Signalization · Graphic symbols

## 1 Introduction

The mobility of people and goods suffered a significant increase in the last decades, aided by the growth of low cost airlines, the growing supply of the number of cruise ships, the high-speed train networks, or improvement of road networks, among other factors, which resulted in greater influx of people to tourist attractions, airports, rail stations, events, accommodation units, commercial areas, public services, etc., which raised the need to target these people in an unknown space and communicate basic messages with a language understood by a majority.

This same mobility brought with it an economic and social development associated to an increasing flow of people moving by various needs from one point to

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another. This displacement, often made on unknown spaces, triggered the need to learn new codes, which become to be formalized through signs that facilitate access to certain places, the circulation of people and goods and contribute to the security of citizens.

The increasingly global democratization in access to goods and services, in addition to the mobility of citizens, allowed access at devices and equipment increasingly present in day-to-day, becoming some of them indispensables in the way of life of countries more developed, such as mobile phones, computer, television, and many other gadgets. These artifacts need to be operated, and therefore it is indispensable to domain the code incorporated in them, expressed through graphic symbols, which allow to recognize roles, tasks, operations and operating mode of these goods.

This research focuses on the study of international standards, particularly which are related with design, standardization and uniformization of graphical symbols, trying to understand if the application of standards into effect in the domain of graphic symbols can contribute to uniformization, understanding, legibility and perception of quality of sign systems for public information, safety identifications and graphical symbols for use on equipment.

It is expected to obtain as a result of the present research a manual where it meets a set of terms, definitions, normative principles and methodologies in the field of graphical symbols that can be applied by professional design, intending to reinforce the graphical and functional quality of the developed visual codes.

## 2 Context

In exploratory studies developed in the area of public information symbols, were detected gaps at the level of application and methodological development in relation to work done by the creative teams (designers). Mostly, the projects result from an empirical process, based on academic training or professional experience, with a focus on aesthetic or technical aspects (related with design or production) or commercials (the economic dimension).

In the development of sign systems for information, in previous studies it was concluded that there is a dysfunction between the project objectives and the real user needs, ie, there is a gap between the objectives of the project teams and the true user needs. In general, systems are conceived based on aesthetic and design aspects, and less on the basis of functional arguments and centered on the real needs of the target audience.

From a methodological point of view, it matters incorporate principles and methodologies that enable to designers and, consequently, to the general public, get more universal sign systems, recognized and user friendly. Such principles are likely to be applied in the projectual development, allowing standardization in the field of graphical symbols as well as colors, shapes, and other graphic elements.

International standards that are related with graphic symbols, being them for public information symbols, safety signs, or graphical symbols for use on equipment, are prepared by the International Organization for Standardization, more specifically by the Technical Committee ISO/TC 145.

These standards contain determinant information for the development of information systems, guidance and safety, therefore a strategic tool for designers and communication companies, helping the design of coherent systems, uniforms and user-centered, allowing a better perception, decoding and retention of messages.

However, despite the important content that international standards presents, they contain a structure and language too technical and rigid, which hinders its adoption by designers and studios, since they contain some principles and symbols that may contradict the methodologies and design processes in use.

It would be important to compile, systematize and reduce to a single document the references normative, terms, definitions and principles directly related to graphic symbols, allowing the appropriation and application of these fundamentals in graphic development of systems and codes conceived by designers, incorporating a new language of universal signs, instantaneous and uniform.

## 3 Design of Graphic Symbols

It is considered as a general principle, in the development of graphics system, that all systems are different, distinct and unrepeatable and with distinct audiences. It is therefore important to consider the issues related to the design of the visual code.

Any image that competes to form a pictogram, tends to take on the characteristics and convey the sense of the total category of objects which belong to the object in examination [1]. That is to say that an image to be represented by a pictogram, tends to regulate the design of other pictograms that are contained in the same category.

Ordinarily, the image of an object has the property to display that object in all its uniqueness, loaded of all attributes that characterize it as unique. In the pictograms should happen otherwise, the figure “man” should serve to “all possible men”.

If it was used a photograph of a man to a signal, the image would be much closer to the real man than the outlined by pictogram, but it would be much less useful. If each figure must serve to ‘the whole set of possible objects belonging to that class’, the figure of which we speak should never foreshadow an object, but the whole class of those objects i.e, a concept [1].

Images have own characteristics that differentiate them from other. According Moles and Janiszewski [2], there are criteria that characterize the different types of images, such as Iconicity/Abstraction; Complexity/Simplicity; Normativity; Universality; Historicity; Aesthetics or cognitive load; Fascination.

The requirement of transmitting information by pictograms obliges to conceive concise, simple and quickly understandable signs; for it, must be sought elementary graphic structures, to do justice to a certain type of perception [3]. In general, the conceptual model (taking into account the design of pictograms) should present information in a more simple, clear and without ambiguities possibles [4]. The design has the unique ability to shape information by certain techniques [4], as the emphasis or understanding; comparison or structuring; Grouping or order, selection or omission; Option for immediate or delayed recognition; presentation in an interesting way.

In psychophysical studies of Max Wertheimer, Wolfgang Köhler and Kurt Koffka, known by the development of Gestalt theory (or psychology of the form), it is considered the perception as a whole and it leave of the whole to explain the parts, being that the whole is not the sum of the parts. The elements of a picture are grouped spontaneously and this organization is innate. The principles of perceptive structuration is organized as follows: Perception figure—background; Perception of the group (Proximity, Continuity or good extension; Symmetry; closure or continuity of contours; Subjective Contours); Perceptive constancies (Constancy of form; Constancy of size; Constancy of brightness and color); Prägnanz or good shape.

The European Conference of Ministers of Transport in 1991, supplementary to the Signs and Road Signs Convention, established basic principles for tourist signs [5], principles such as the Principle of safety; Principle of proximity; Principle of specificity.

According Avillaneda [6] for developing a signal system, it is essential to define the bases of creating a set of signs or graphics, because the strict observation of each normative basis will be reflected in the signaling system functionality. It is defined the following normative foundations [6]: Coherence; Logic; Terminology; Location; Clarity and precision; Color; Design; Flexibility; Universality.

According to Carlos Roque, the task of driving involves a different set of conditions associated at a space, a road, at a precise point and occurring simultaneously. Then it becomes necessary the understanding of the system by the driver, which is closely related to their overall perception (how the system works) and your relationship with the other actors of the same system. Also the legibility of the road influences the driver's behavior towards the system, allowing to adapt more easily to the system.

It is understood that the signaling can effectively contribute to the readability of the road, although not, by itself, enough to ensure it. Thus, a signaling system must take into account the following principles: Uniformity; Homogeneity; Simplicity; Continuity; Coherence.

## 4 Standardization of Graphic Symbols

Around the world, numerous signaling systems have been developed in the area of public information, yet do not share common codes, being projected for a particular entity or territory, with a unique character, isolated from other systems, far from the desired universal character for guidance systems and public information.

Examples of systems developed for public information are plentiful, such as applied by countries, regions or tourist authorities, provinces, municipalities, tour operators, businesses and many other organizations. Yet, it is truly impressive to see that, in general, the systems do not relate to each other, often causing difficulties in accessing certain places, reducing the mobility of users.

It is verified often the implementation of vertical signaling systems (traffic signalling) in conjunction with tourist symbols (which is applied in touristic establishments and by tourism operators). There are also systems applied in some regions by local municipalities or companies dedicated to tourist activities. As easily understood, the several referred systems generate, for the user, redundant messages or often, the lack of information by the huge deregulation and lack of uniformity in the messages to be transmitted.

Important example in the context of this research, is the project developed for the signaling program developed to a set of facilities linked to the transports in the United States, selecting for this purpose the American Institute for Graphic Arts (AIGA). The system was designed to guide people and goods in places with a large influx of users as airports, railway stations, international events, etc., as well as in attempt to devise a system that communicates clear and legible messages at a certain distance, destined to people of different cultures, social classes and age groups.

In attempt to standardize, in 1993 the World Tourism Organization (UNWTO-WTO) launched the publication "Signs and tourist symbols", which presents concepts and terminology used in the tourism sector, as well as a set of 290 symbols for public information and touristic. The publication refers to activities undertaken by UNWTO the 1998–2000 period corresponding to the matters relating to standardization and technical standards. The edition is the result of a survey by the national tourism management agencies worldwide, as well as international organizations linked to the sector. It is considered the study published as an embryonic attempt of classification and standardization of symbols for tourist information, but without great results, limited to present and select the symbols without methodology, in an empirical way and not relating the symbols in an attempt to create a common code.

Thus, it were verified over time several attempts to standardization and normalization of graphic symbols present in guidance and indication signals, highlighting the work of the ISO Technical Committees (International Organization for Standardization), which highlights some Standards and Technical Reports related to the symbols for public information. Because of its importance and technical rigor, we refer, in a further way, their contributions to the standardization of graphical symbols to indication signals as a result of this investigation.

The technical report ISO TR 7239: 1984 presents the procedures of development and principles for the implementation of the symbols for public information, addressing the report three major areas: procedures for the development or adoption of symbols; the criteria of visual design; the implementation process of the symbols for public information [7]. Establishing the necessity of the existence of a new symbol, the development of this should be based on the results obtained in the normative process [7].

Regarding the content of the normalized image, the ISO 7001 standard establishes three elements: (a) the standard image content; (b) the function; (c) application field. For the construction of a symbol, the Report indicates that the use of grids can help to keep the apparent size similar and consistency in symbol sets. A variety of visual components that should be used in public information symbols prevents, however, the use of restrictive geometric patterns. None of developed symbols should be forced to fit in a basic grid, in detriment of their communication.

Already the standard ISO 22727: 2007 sets out some guiding principles for the creation and design of symbols for public information, being these principles organized into three parts: the process of creation, function and meaning, and finally the design of the graphic symbols [8].

The standard in analysis indicates some additional guidelines for the design of the symbols for public information, which is considered to be important for the development of graphic signs to incorporate into sign systems for tourist information, as regards Filled areas; Symmetry; Abstract symbols; Directional arrows; Representation of the human figure.

Checklist for designers: It is recommended that the designer, during the creation and design of a graphic symbol for use in public information, addresses the following questions, in order to solve a problem of public information identified: Meaning; Meaning(s) alternative(s) accepted; Meaning(s) Unintentional; Function; Need; Existence of public information symbols; Existence of graphic symbols and graphic symbol elements; Application field; Target Audience; Other details to specific audience; Related meanings; Denial; Review project; Test data.

The system design is one of the most important stages and which will give body to the signaling system. It should be reviewed all the basic aspects of the system, then the concepts of the project should be defined and even the design of the supports and the graphic design of signs. After analyzing the results, should be collected comments and suggestions to reformulate or further development and thus pass the validation phase of the symbols. Thus, there are several tests to validate the designed system and in particular the ratio of its constituent elements. It presents, next, several tests that aid in the validation task of graphical symbols.

## 5 Validation of Graphic Symbols

The operationalization of the design procedure of signaling systems it is composed by various activities and steps, which concretely operationalize the design tasks, normalization and validation of graphic symbols of the indication signs.

The system design is one of the most important stages and which will give body to the signaling system. It should be reviewed all the basic aspects of the system, then the concepts of the project should be defined and even the design of the supports and the graphic design of signs. After analyzing the results, should be

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The conventionals usability tests have origin in computer sciences, which aims to assess the interaction of the object with the user. Specifically, for the present research and for the thematic of guidance and signposting systems, Usability Test it is defined as that who evaluates the relationship between graphic symbols of guidance and indication signals with the user.

In this sense, the Usability Testing is crucial to evaluate the graphic and functional quality of the symbols and their ability to communicate with the user. There are four types of usability testing: The exploration test, evaluation, validation and comparison.

The Exploration Test it aims to evaluate the effectiveness of the preliminary symbol (in sketch or mockup) and meet the opinion of the user of developed model. It is applied when the artifact is still in a draft stage, that is, is indicated for the start of the project in order to make an analysis of the design and evaluate the understanding of the user.

As for the Assessment Test, this aims to continue the preliminary assessment carried out in the Exploration Test, which aims to assess and test if the previous concept was implemented effectively, ensuring that the user decodes the message, understanding the meaning of graphic symbols. For the test, must be developed surveys where the symbols approach the final object.

Concerning the Validation Test, it aims to determine how the symbols behave before the established standards of ergonomic point of view, from shape, color and graphism, among others, as well as from the point of view of the quick and clear decodification by the users. The validation test occurs at the end of the process, to measure the performance of symbols, sometimes tested in a real context, in the environment where it will be applied.

The Comparison Test, as its name indicates, aims to compare different graphic symbols and it can be applied at different stages of the process. The test serves to qualitatively assessing the intrinsic characteristics of different signs, requesting to the user a comparative evaluation. In the early stages of the process can be used to compare differences in graphic style between different symbols, in a intermediate phase may be applied to measure the effectiveness of a symbol or parts thereof and, at the end of the process, can be used to evaluate the system developed with other systems in use. The comparison test can be used as a junction of the various tests, and its objective is the admeasurement of the characteristics of a graphic sign or its constituent parts.

The Visibility Tests "in situ" are intended to evaluate the graphic and functional quality of symbols system developed, as well as their ability to communicate with the user and applied in space or territory in validation. The test involves developing models to scale 1:1 as faithful as possible at the original to apply, under the same lighting conditions and preferably with the same supports, materials and the with the same dimensioning previously defined by the project team. Thus, it is a final test of the system, in real physical conditions, where should be selected a random sample of the target audience and can select a group of experts in the area that may also be asked with the test.

Thus, visibility tests are applied in a “real” physical space, where is wanted to apply a final visibility test. In certain cases, tests simulate different lighting conditions, different screens, materials or color tones, in order to select the final materials that will constitute the supports.

The comprehensibility tests results of the application of the standard ISO 9186-1: 2007 (E), which specifies methods for testing comprehensibility of the graphic symbols, including: (a) the method to be used to test the amplitude a variant in which a graphical symbol communicates the intended message; (b) the method to be used to test which variant of a graphical symbol is judged as more understandable. The ISO 9186-1: 2007 (E) presents two types of test: The Comprehension Test and Judgement Test.

The Comprehension Test is a procedure that is intended to qualify the understanding of a graphic symbol proposed. It is based on qualitative assessment of the responses on the assessment of a particular sign. Respondents are asked to indicate what is the meaning and what action it would take in response to a presented symbol. The objective of this procedure is to determine what action developed by the users in front a given symbol and is recommended especially for an advanced phase of the graphical development of solutions.

The Judgment Test is a procedure for the quantitative assessment of the understanding of a graphic symbol proposed. It is based on the judgment of several presented symbols to respondents, where it be indicated the percentage of understanding of a particular sign.

This estimate is given by each respondent, at who are asked to indicate what percentage of people who, in their opinion, correctly understand the meaning of data pictogram, symbol or icon. The objective of this procedure is to determine, quickly, what the signs that have the greatest potential for understanding and is recommended especially for the early stages of the graphical development solutions.

## 6 Outcomes

This research project is in an intermediate state of development, in which is intended to provide guiding principles for the development and validation of graphic symbols. However, in result of previous investigations and research already rolled out, it was possible to reach preliminary results, which substantiate and pre-validate the stated research questions.

Of the work performed, it is considered that the guidance and public information systems are not developed in a systematic way and do not know (in most cases) the application of principles for the development, standardization and validation of signaling projects or signage.

Considering this problem as the starting point for this essay, where it reached certain principles that can consolidate knowledge in the study area and have implications for improving the graphical and functional quality of the visual code. It was possible to define principles applied in the development of graphic symbols for integration into public information programs, which are enunciated in summary: Principle of Need; Principle of universality; Principle of participativity; Principle of usability; Principle of simplicity; Principle of uniformity; Principle of normativity; Principle of perceptibility.

It was also possible to determine a set of international standards and methodologies applied to the conception and development of signage programs for public information, while is in developing the compilation of these international standards (ISO) and methodologies, in order to obtain an important tool for designers and studios that are operating in the field of signage and wayfinding, looking for a set of guidelines for the development, standardization and validation of graphic symbols present in signage programs.

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# Systematic Pattern Code Design on Kitchenware for Operable Activities in Tangible User Interface

**Fong-Gong Wu, Pin-Chin Wang and SuHuey Tan**

**Abstract** This research has developed a new operation way of using pattern codes to operate the tangible interface of kitchenware for a smart family environment. This new development allows users to control products such as stereos and light switches using different utensil operation postures. Focus group was conducted to extract elements for pattern designs to develop pattern codes. The pattern codes are required to be both recognizable by programs and to be able to communicate the suggestions of operation to users. During the evaluation stage, tests for the program recognizable rate and subjective evaluation questionnaires were both conducted in order to evaluate the possibility of implementation of our pattern codes on the tangible user interface. The test results show that the pattern codes are recognizable by the computing programs, while the subjective evaluation results show that the patterns successfully communicate the suggestions of operation and semantics to users. Finally, this research concludes that the pattern code design conforms to both the recognition of computer visuals and users. In terms of future development, the pattern codes can be extensively applied to household objects, to both operate and interact with the smart family system through the identification system, creating an innovative object recognition system.

**Keywords** Pattern code · Tangible user interface (TUI) · Feedforward

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# 1 Introduction

With the commercial success of the Apple Macintosh and Microsoft Windows systems, the graphical user interface (GUI) has become the standard paradigm for human computer interaction [1]. People utilize the GUI to operate computer software and interact with the digital world instead of the innate human activities and capabilities in the physical environment. In the mid-90s, Tangible Media Laboratory of Massachusetts Institute of Technology (MIT) started to focus on TUIs instead of GUI in which the key idea of TUI was "to give physical form to digital information". However, many studies of TUIs encountered restrictions in usage in the control settings [2] and the limited interactive field [3]. Moreover, researchers have to deliberate whether users understand completely the meaning of each manipulative object in TUIs. Hence, we intent to use pattern recognition as a tool to solve these problems.

Graphic has always been assessed as a good method to convey a large amount of information effectively [4]. However, Horton [5] noted that all the meanings of graphic originate from people's association, experiences and memories. To convey the information of graphics, it requires not only the graphic composition but also the perception of humans. Furthermore, the graphics used in pattern recognition technology nowadays is generated by algorithm; they do not comply with personalized aesthetic and human cognition [6]. Humans cannot recognize most of the 2D pattern codes that were applied on commercial field without computer decoding.

Among the pattern recognition algorithms, Speed Up Robust Feature (SURF) detects interest points on patterns with the feature of scale-invariant and rotation invariant [7]. As the accuracy rate of recognition would decrease with change of perspective, descriptors, which is the feature vectors around every interest points, should be set to increase the accuracy rate. SURF algorithm recognizing the different descriptor based on distance arrange that the distance be defined to the difference of physical quantities, such as interval, area and proportion of the relative position. Hence, the graphic features of boundaries, interest points, descriptor, and distance are the factors that influence pattern recognition.

The purpose of this study is to develop a systematic pattern code design to allow intuitive user interaction with the smart home system in TUIs. According to the categories of usage field and function, we conduct to design a corresponding pattern code that suggests the corresponding function of each key, and making it a target of recognizable detection.

# 2 Method

This study is divided into two parts. Part 1 is to develop pattern code units, while part 2 is to evaluate the pattern code design in reality. The experiment field set on dining table. Plates were used as the medium of pattern codes. Boundaries, interest

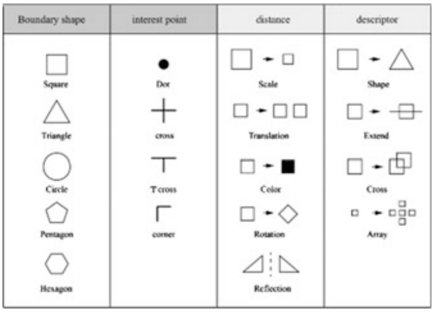



**Fig. 1** The primary morphological chart for pattern code design

points, descriptor, and distance are the factors that influence pattern recognition. These four factors were used to constitute a primary morphological chart for the pattern code design. As shown in Fig. 1, the column of function is the pattern feature of recognition by human and computer while the row of means lists all possible pattern code units and structural rules.

## *2.1 The Development of Pattern Code Design*

In order to make pattern code can conform to cognition and provide user pleasure, we would conduct the experiment in two stages, (1) Extraction of utensil attributes and pattern code unit design by focus group; and (2) Conforming to the principle of computer vision and cognition, and utilizing pattern code units to design pattern code with the feedforward of interactivity.

### 2.1.1 Stage 1: Focus Group

**Participants**

The participants were selected amongst college students because the students are the next generation of users of TUIs. In order to develop aesthetic pattern codes, the participants chosen were design major students with at least 2 years of learning experience in the field. Their ages range from twenty-five to twenty-six years.

**The first stage of focus group**

During the first stage focus group, two focus groups were conducted altogether with six participants in each group. Each focus group lasted between 40 and 90 min. The purpose was to extract the object attributes from kitchenware and utilize these attributes to design raw pattern code units. We chose nine frequently used kitchenware, including plates, bowls, cups, knives and spoons, spice jars, shovels, soup scoops, cutlery, and kettles. According to the model of object attribute extraction proposed by Chen and Owen [8], participants are required to write two adjectives for each kitchenware. Then each participant shares the definition of

**Fig. 2** The initial adjective pairs for the semantic differentials

| | | | |
|---|---|---|---|
| Adj.1 | Explicit / Ambiguous | Adj.10 | Calm / Impetuous |
| Adj.2 | Mobile / Motionless | Adj.11 | Orderly / Chaotic |
| Adj.3 | Familiar/ Unfamiliar | Adj.12 | Stable / Unstable |
| Adj.4 | Easy to identify / Difficult to identify | Adj.13 | Fast / Slow |
| Adj.5 | Safe / Dangerous | Adj.14 | Moving / Static |
| Adj.6 | Easy and relaxing / Tense | Adj.15 | Smooth / Circuitous |
| Adj.7 | Spacious / Packed | Adj.16 | elevated / dropped |
| Adj.8 | continuous operating / Switch operating | Adj.17 | synclinal / Flat |
| Adj.9 | Moving forward / Moving backward | Adj.18 | Attractive / Ugly |

adjectives and the reasons for choosing them. During this phase, all participants utilized the KJ method to cluster the adjectives of object attributes that they proposed into several groups, and gave each group a title. So that the specific object attributes would be obtained. After that, the participants were asked to design appropriate pattern code units according to the perceptions of summarized attributes.

**The second stage of focus group**

The second stage focus group was conducted with six participants in order to assess the evaluative standard for interactive pattern code and develop pattern codes which are able to give an interactive feedforward. At the beginning, participants would receive a list consists of eighteen adjective pairs, shown as Fig. 2. The moderator would interpret the definition of each adjective pair, and then explain the aim to the participants. The participants were asked to select the adjective pairs they feel appropriate to be deemed as the evaluative standard of operational feedforward on pattern codes. The Collection of adjective pairs for the semantic differentials was done according to the research that Chang [9] evaluated to the guidelines of Emergency Signs in hospitals. Through sieving adjectives pairs out, it allows participants to understand the evaluative standard of pattern codes, therefore the rationality of pattern code could be promoted. The adjective pair left out of the selection would be utilized in the SD method that measures the subjective perception for pattern code design.

Participants were then told that the pattern code would be applied in TUIs as operable patterns, and it would be attached on a plate to interact with systems around the dining table area. Then participants conducted to pattern code design.

### 2.1.2 Stage 2: The Encoding Structure of Pattern Design

After the aboriginal pattern code design and the pattern code design were proposed, we aimed to encode the data in the pattern codes that were recognizable. The selection and utilizing of 2D barcodes must include the consideration of the following factors: (a) the application, (b) the standard, (c) the implementation, (d) the data you need to encode into the barcodes, and (e) how you wish to print the barcode Gao [10]. QR code, which is the most widely used and popular two-dimensional bar code, consists of several parts, i.e. Finder Pattern, Separators, Timing, Alignment, Format, Data, Error correction, and Remainder Bits. Therefore, we determined the factors that we required in order to develop the structure of pattern codes. In the kitchen, pattern codes are only required to present the kitchenware in the computer vision and provide operable feedforwards to users. Therefore, Finder Pattern, Separators, Timing Pattern and Data are the four features of two-dimensional code we employed as the basic factors of pattern code design.

When the pattern code encoding was conducted, we found three robustness mechanisms in pattern recognition. They are check area, validation regions, and redundancy [11]. Check area means a complete graphic code containing encoded data range. Validation regions mean there are a fixed number of features that can be recognized. Redundancy is that replicating the code increases reliability if part of the pattern is obscured by food or specular reflections. We can replicate pattern codes in different positions on the kitchenware, to allow algorithm a bigger change of successfully recognize the pattern code correctly. Hence we do not need to set the capability of error correction in the pattern codes.

## *2.2 The Evaluation of Pattern Code Design*

The evaluation would conduct to assess subjective perception of users whether the pattern codes provide sufficient feedforward to convey to them the operation in the TUIs. The rate of pattern code recognition would be measured by the SURF algorithm to evaluate its performance in computer vision. The subjective perception was measured by SD method to assess the comprehension and acceptance of users towards the pattern codes. Besides, the pattern code would be printed and put on the plate, and then the testing of recognition rate would be conducted under a controlled environment to confirm whether the pattern code was effective in reality.

### 2.2.1 The Evaluation of Subjective Perception

The Semantic Differential Scale is assumed that adjectives can be used in a rating process to measure the subjective perception associated with the attitude of participants [12, 13]. The questionnaire was designed to measure whether users could comprehend the feedforward of pattern code that prompts user to do certain action. The participant was asked to place a mark in the line between a pair of adjectives to express his or her feelings toward the measurement object. The selection of adjective pairs was based on the result of the second stage focus group. We divided the pattern codes into two groups according to experiment results, a group that had the operable feedforward and the other without. The participants were selected from the public in order to obtain a more general insight to pattern code design results. The result would be analyzed by using the method of factor analysis.

### 2.2.2 The Recognition Accuracy Testing by Algorithm

The definition of recognition in this study was that algorithm captures the image and successfully matches it with the model image. In order to test the pattern code, we put it into a controlled environment and set up cameras on the top of the working platform. The pattern codes were made into stickers and affixed to plates as the target of recognition. Each test includes a set of operations done within 1 min, for a totally of three times. The work area is a pure white desktop, without any other objects to interfere with the proceeding of pattern recognition. The camera to captures the pattern on the plate while the participants operate a set of actions including handling, rotation, stationary, tilt, movement and placement, allowing the algorithm to detect the pattern in dynamic and in different angles. The uniform light source was set as ambient lighting to reduce the surface shadows or surface reflection light due to uneven illumination.

The SURF algorithm conducts to recognize the pattern code with the following steps: (1) Given a search range (Mean Shift Algorithm), (2) capture Surf feature, (3) feature intensity defined (a line represent feature similarity between current image and model image), (4) whether feature intensity is greater than 0.68 %, (5) feature matching amount is greater than 4 lines. If SURF algorithm did not successfully detect the pattern that corresponds to the model image, the searching area would conduct back to the center of the camera vision and extended 10 % of the searching area to search again. If SURF algorithm successfully detects a matching image, the pattern program would capture the image then update the position of the target pattern to re-determine the search range. The average of recognition numbers was calculated and the researcher would check the result image to calculate the rate of successful recognition.

# 3 Results

## *3.1 The Pattern Code Design*

After comparing titles and adjectives of each group, we can summarize that the feelings towards material and towards form, function and usability, the feeling of haptic, external dynamic performance, inner experience and memory, and kitchenware operation experience. Participants designed pattern code units according to their associations with the attributes of kitchenware. We retained two hundred and ten raw pattern code units for analysis. Three domains of product attributes (performance, appearance, and communication) were utilized to categorize kitchenware attributes. The geometric shapes, line shapes, radial shapes, and organic shapes were chosen as selective standards to conduct pattern code unit selections. The selection of pattern code units was based on simplicity and geometric shapes. The results of the selection are shown on Fig. 3a. A total of forty code units were chosen as the final pattern code units and we put these units into the

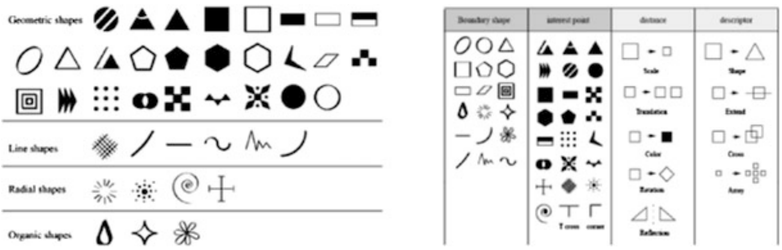
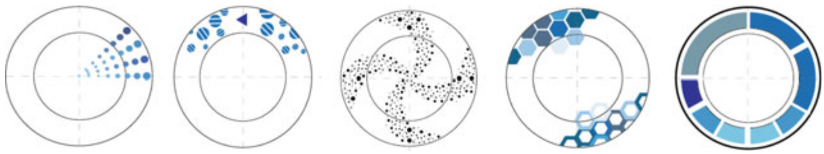



**Fig. 3** **a** The final pattern code units, **b** the final morphological chart



Code 1 Code 2 Code 3 Code 4 Code 5

**Fig. 4** Pattern codes

primary morphological chart. The final morphological chart is used as the design tool for the pattern code design (as shown in Fig. 3b).

For the initial result, we collected twenty-four pattern code design concepts in total. According to the indicators of the principles of pattern code design, such as easy-coding, beauty and feedforward, participants assessed the feasibility for each pattern code design they proposed. Five pattern codes were selected for the final result. These five pattern codes are shown in Fig. 4. The pattern code of Code 3 showed the best feedforward to prompt users on how to operate specifically. Although the feedforward of the pattern code of Code 5 was not significant, the aesthetics and coding feasibility were assessed to be the best. The result proposed two kinds of pattern codes and both were aesthetics. One pattern code possesses interactive feedforward, shown as figure Code 3, and the other does not possess interactive feedforward, shown as Code 5.

## 3.2 *The Evaluation of Pattern Code Design*

### 3.2.1 The Evaluation of Recognition Rate

SURF algorithm was used to test the two above-mentioned pattern code designs (Pattern code A and Pattern code B) in the real environment. We utilized plates as operational mediums to attach the pattern codes to, showing in Fig. 5. We placed pattern code A and pattern code B as model images for the two groups respectively

**Fig. 5** Pattern code A and pattern code B

to conduct the recognition rate test. The algorithm was placed with two model images for each group. One model image was vector graphic and the other model image was a real picture with pattern codes on plate.

**The testing result of pattern code A**

The comparison picture was recorded and generated automatically by algorithm. The model images of real pictures and the examples of comparison results are showing in Fig. 6a. The results of the three tests showed a recognition rate of 87.77 % for pattern code A. SURF algorithm recognized images for a total of ninety times, that is an average of thirty times per test, and an average of 4 s for each recognition. In 1 min, pattern code A can be correctly identified 26.33 times. According to the results of the three tests, we conducted to make a statistic for recognizing points and the result is showing in Fig. 6b. The positions of color dots represent where the correct recognition took place. The two kinds of model images in the algorithm are represented in the two color dots. Green color presents the model images of the real picture, while purple color presents the model images of vector graphic.

As Fig. 6b shows, we can see that blank spaces were also regarded as recognizing features and that 56.52 % of the recognition took place in the blank spaces. But the blank space is near the center of the pattern and it is not too far from the feature points. Moreover, the positions of recognitions are spread evenly and do not tend to concentrate in certain areas. When the plate was rotated, the algorithm also captured twenty times in total with nineteen correct recognitions, showing a recognition rate of 90 %. It showed pattern code A can be well recognized even in rotating conditions.

**The testing result of pattern code B**

The model images of real picture and the examples of comparison results are showing in Fig. 7a. The result of the three tests showed that the recognition rate of pattern code B was 73.95 %. SURF algorithm recognized images one hundred

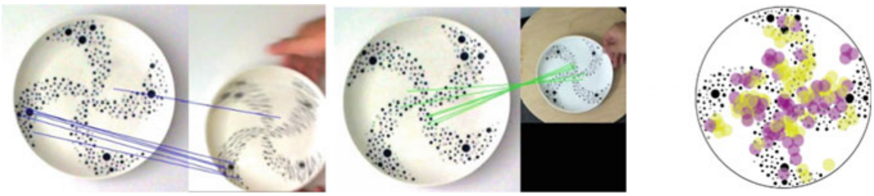


**Fig. 6** **a** The examples of capturing pattern with model images of real picture, **b** the result of testing pattern code A

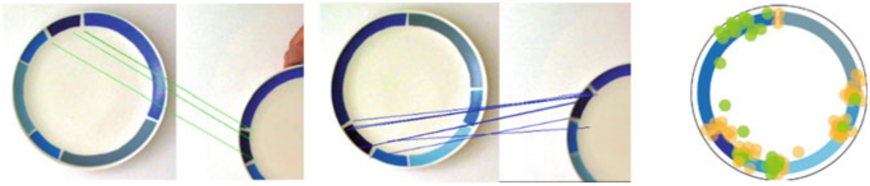


**Fig. 7** **a** The examples of capturing pattern with model images of real picture, **b** the result graphic model

nineteen times, an average of 39.67 times per test, an average of 3.02 s for recognition. In 1 min, pattern code A can be correctly identified 29.34 times. According to the results of the three tests, we conducted to make a statistic for the recognizing points showing in Fig. 7b. The positions of color dots represent where the correct recognitions took place. Yellow color presents the model images of real picture. Green color presents the model images of vector graphic.

As Fig. 7b shows, the recognizing features tend to take place in corners of shapes. 66.27 % of the recognitions taking place in corners, and 27.71 % of recognitions taking place in the edges of shapes near corners. This result can verify that the design of utilizing corners as interest points is correct. When the plate was rotated, algorithm also captured forty-one times totally with thirty correct recognitions. The recognition rate when the plate was rotated is 73.17 %. It shows that pattern B can also be recognized well even in rotating conditions.

Finally, according to the results of pattern code A and pattern code B, the comparison between pattern code A and pattern code B would be conducted. At first, pattern code A not only showed better recognition rate but was also recognized better in rotating conditions. However, in 1 min, pattern code A can only be correctly recognized 26.33 times, while pattern code B was correctly recognized 29.34 times. It showed that pattern code B is in fact more efficient than pattern code A. The reason was that the form of pattern code B is much simpler than pattern code A. The form of pattern code B was a ring shape, and the algorithm was able to focus on the area of the ring rather than having to search the entire surface of the object. Moreover, the application of interest point of pattern code B is also simpler. So we can conclude that pattern code A is better when applied in rotating conditions, while pattern code B is more appropriate for applications under normal conditions.

### 3.2.2 The Evaluation of Subjective Perception

Fifty-one questionnaires of subjective perception were collected during three days. The mean of each evaluative standard of the two different pattern codes are drawn as a line chart shown in Fig. 8. The result of two-pair T-test to compare these two kinds of pattern codes is shown as Table 1.

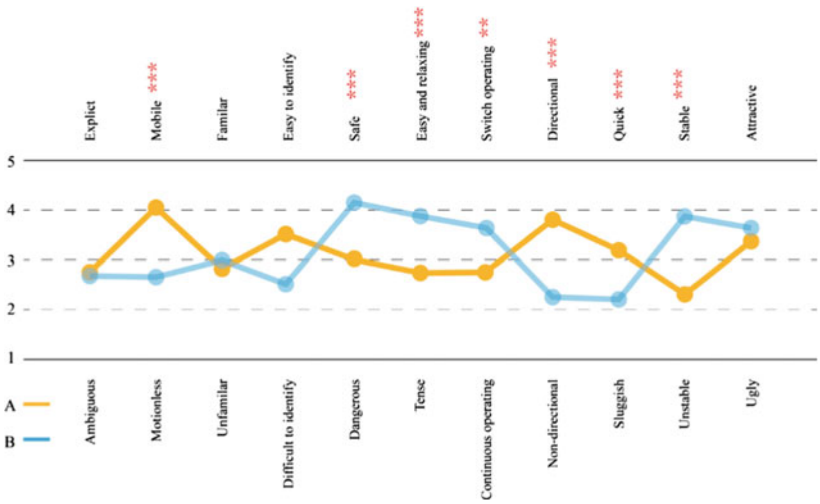



**Fig. 8** The result of SD method

**Table 1** The result of paired-samples *T*-test

| Adjective pairs | t | df | Significant (two tail) |
|---|---|---|---|
| Explicit/Ambiguous | −0.092 | 50 | 0.927 |
| Mobile/Motionless | −6.711 | 50 | 0.000 |
| Unfamiliar/Familiar | −0.871 | 50 | 0.388 |
| Easy to identify/Difficult to identify | −0.362 | 50 | 0.719 |
| Dangerous/Safe | −5.82 | 50 | 0.000 |
| Easy and relaxing/Tense | 6.272 | 50 | 0.000 |
| Continuous operating/Switch operating | −3.229 | 50 | 0.002 |
| Non-directional/Directional | 5.196 | 50 | 0.000 |
| Quick/Sluggish | −4.759 | 50 | 0.000 |
| Stable/Unstable | 7.575 | 50 | 0.000 |
| Attractive/Ugly | 1.067 | 50 | 0.291 |

As Fig. 8 shows, the evaluation of pattern code A was presented as yellow points and lines. In the subjective evaluation of pattern code A, the description "mobile" (4.02) received the most points and "directional" (3.80) came second, meaning that participants think this pattern gives them a dynamic perception. In the qualitative descriptions questionnaire, 86.27 % of the participants proposed that they think this pattern should be operated with a rotation. It verified that the design concept of this pattern code was being conveyed correctly. The description "unstable" and "quick" also received significantly higher points than the others.

The description "non-directional", "stable", and "easy and relaxing" also received significantly high points, and these descriptions all refer to the same perception. Looking at the qualitative results, 49.02 % of the participants think it should be operated through rotation in pattern code B, while 31.37 % of the participants think it has to be held up for operation. Several participants even think it can be operated as a remote control. The description “struggle” and “switch operation” also received high points. The result also reflects that participants think it could be used to conduct static operations in TUIs. So we can conclude that pattern code B is more appropriate for static operation than dynamic.

## 4 Discussion and Conclusion

It is difficult to associate the graphic form of aboriginal patterns with usability and operation since most participants evaluated this pattern code as less aesthetic. Swirl pattern codes are suitable in prompting users to conduct dynamic operations due to its high evaluation in terms of directional, mobile and continuous operation. The form of flow is evaluated as more aesthetic than the form of polygon and line, because it prompts a specific motion effectively. Moreover, compared to polygons, the form of flow suggests a natural rather than digital form to participants.

From factor analysis, we learned that the factors for the formation of semantic meanings of the pattern codes are (a) operable feedforward, (b) emotional perception and (c) dynamic presentation. In this study, we learned the form of flow not only can be utilized to prompt people to do a certain operation effectively, but are also able to enhance the emotional perception through natural and streaming graphics. The form of flow are also useful in presenting dynamic aesthetics. In this study, we found that putting data module into a form of flow is feasible. Moreover, compared to previous pattern codes, the form of flow is a new presentation of pattern code design. Therefore, we propose the form of flow as the main structure of pattern code. Furthermore, we adjust the design of swirl pattern code by enhancing the design of interesting points to promote recognition speed and make framework simpler. The template of the final pattern code and examples are shown as Fig. 9.

For practical consideration, the center of the plate would be covered by placed objects, so the pattern code in the center of the plate would be for decoration purposes only. The pattern codes for recognition would be focused on the ring shape near the edge. Considering this, redundancy was utilized to present data modules repeatedly. In reality, shadows need to be considered as they may cover up pattern codes. The activities in the field of kitchen should be investigated in detail and we expect to apply this pattern code representing the dynamic operation and static operation in TUIs and allow TUIs to provide more interactivities to users. Consequently, enhancing the recognition frequency and utilizing pattern codes on

**Fig. 9** The template of final pattern code and examples

diverse kitchenware of different sizes simultaneously, would be an important issue on pattern recognition in the application on TUIs.

The attributes of kitchenware have been extracted in the first stage. It can be utilized to help designers comprehend the population stereotype of human on objects, which may be useful in helping designers to develop more intuitive TUIs and make tangible interactivities closer to human life [14]. Object attributes can also be used to describe and explore the schema for objects, so the basic concepts of object for operation can be found. It can help researchers develop more intuitive operational methods for users and help researchers understand how to utilize pattern recognition appropriately in TUIs. Furthermore, we can also utilize this pattern code in other kitchenware and adjust pattern code designs according to these attributes. To consider the application of circumstances of each kitchenware, the position of pattern code should be assessed carefully. Through putting diverse pattern codes on different kitchenware, we can investigate and develop interactivities in the kitchen area in the future.

The present study enhances the experiences of using pattern codes by providing more understanding on pattern designs from its graphic structure. Comparing with the current two-dimensional codes, such as QR code, the pattern code in this study is more aesthetic and conveys better the meaning of its graphic representation. The pattern code also provides good feedforwards to users, indicating the correct operation. The beautiful pattern can even elicit the curiosity of users to encourage interaction. These findings are in line with previous studies, although no previous study has discussed this question in detail. The results of experiment reported in this study have demonstrated that these new pattern codes can be practically implemented and provide adequate results.

More research is definitely required on the effects of environment context toward the usage of pattern codes in TUIs. In this study, we successfully concluded the use of pattern codes as a medium to present interactivities in smart homes, and have found that the three factors of pattern code designs are operable feedforward, emotional perception, and dynamic presentation. In the future works, we expect to use pattern recognition to make the operation of TUIs more intuitive and to further conform user needs and experiences. Further, we expand to explore the usability of TUI, make interaction more intuitive and the concept of operation more clearly. According to the development of a series of systematic pattern design code in this study, we expect to achieve the object recognition system innovation of TUIs in the future.

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# Study on Design Principle of Touch Screen with an Example of Chinese-Pinyin 10 Key Input Method in iPhone

**Xiaoli Wu and Tianyang Xi**

**Abstract** In the system of human-machine interaction, users access information from interfaces by cognitive mechanism. And send command to the machine by touching screen. So visual perception and users' operation are two key process in human-machine interaction. Interface design can affect degree of comfort and fluency of human-machine interaction. In this paper, to Chinese-Pinyin 10 key input method interface in iPhone in the system iOS9.2 as an example, the study begin with tree interface design orientation: dimension design, color features and arrangement of elements. Then extract characteristic factors of the interface and analysis availability of the interface design by using visual search principle and human-machine principle. And finally summarize the general rules of the human-machine interface design.

**Keywords** Touchscreen interface · Chinese-Pinyin 10 key · Visual perception · Design principle

## 1 Introduction

At present, touch-screen device has been widely used in people's daily life, and laid a foundation for apply of touch-screen interaction. This interactive mode get rid of mouse and keyboards and become more natural and without constraint, which brings to users more interactive space, more freedom of interaction and more realistic interactive experience [1]. So, how to make users naturally, without

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ambiguity and efficiently recognize content of interfaces and make right operation is an important subject in the field of human-machine interaction.

Miaohui [2] has summarized, users' intuitive understanding to interface information in the process of using products is not the product which passively accept the stimulation of information, but the product which after cognitive process of brain. Liangrui [3], among others has discovered that cognitive psychology is a senior psychological process, which based on feeling, and then encoding and decoding, storage and extraction. In the other word, it is a process of perception, memory, thinking, reasoning, and problem solving. Zeng [4], among others has pointed out, the elements in the interface in line with the user's cognitive characteristics and psychological needs, can be more easily used and improve the search efficiency. Egeth [5, 6], among others, has discovered, users will occur in selective attention, even the direction of the line of sight unchanged, so users driven by intention in the process of search for the targets. Wu [7], among others, has studied out the cognitive deviation cause the user error and has classification the user's error [8]. And visual search play an important role in the process of Human-Computer interaction [9].

Base on the rules of cognitive psychology, a series of characteristics of the interface can affect the user's visual perception and operation. In this paper, we will draw a conclusion about how these design elements affect the human-machine interaction process, sum up the factors in favor of human-machine interaction, finally obtain the general rule of touch screen interface design.

## 2 The Model of Human-Machine in Touch Screen

In the process of touch manipulation, users access information from interface through visual perception, and then according to brain's understanding and judgment to information in interface, users give commands to the machine by fingers. According to this process, we build a human-machine model of touch operation (Fig. 1). Visual perception and touch manipulation are two key process connect users and machine interface. Many design elements like size, color, and arrangement have effect on these process.

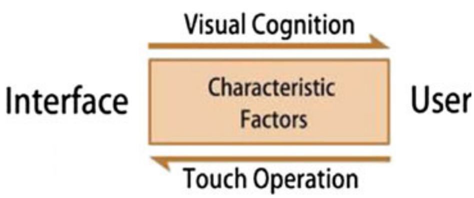


**Fig. 1** The model of touch interface

## 3 Analysis of Design Elements in Touch Screen Interface

In the case of Chinese-Pinyin 10 key input method in iPhone iOS9.2, we analyze design factors on touch screen interface. The touch manipulation behavior is controlled by size of fingers and keys. If the key size is too small, or arrange too closely, fingers wouldn't allowed to touch the target key correctly so that misoperation is occur. If there is no corresponding feedback after a single operation, users cannot determine whether the operation succeeded, they may repeat the operation and result in errors. Good touch screen interface should avoid these factors impede human-machine communication, and make the information in the interface more easily understood.

### *3.1 The Classification of Design Elements*

The function of touch screen is input and output information. Touch screen has varies of function and style, each icon has it's particular shape, color, size, meaning expression [10]. We called this particular character as "characteristic factors". These factors determines whether the interface conforms to the physiological and psychological habits of users. We extract some characteristic factors and analyze how every factor impact users using the interface, then screen out factors conducive to the human-machine communication.

According to different property of design elements, classify these factors into tree category: dimension design, color characteristics, arrangement of elements. Characteristic factors of each category have the same property, so that we find out what effect they have in human-machine interaction. Analyze the design principle of touch screen interface from these three kinds of categories, and study out the right design direction of touch screen interface.

### *3.2 Extract Characterization Factors*

According to these classification of design elements, we analyze and describe the Chinese-Pinyin 10 key interface in detail. Then find out design character and extract characterization factors of interface design.

From the Chinese-Pinyin 10 key input method interface (Fig. 2) we district the interface into four part named ①, ②, ③, ④ (Fig. 3).

After confirmation of the partition, we analyze character of interface design in detail and then describe it with concise words.

**Fig. 2** The keyboard introduction


**Fig. 3** The four part


(1) **Dimension design**

Describe in detail: The size of Chinese-Pinyin 10 key input keyboard is different because of the different size of iPhone screen. In the case of iPhone6, the size of it's keyboard is 56 × 31.6 mm, and the size of every keys are: 11 × 8 mm, 5.5 × 8 mm, 22 × 8 mm, 11 × 16 mm (Fig. 4).

Characteristic factors: the size of each part.

(2) **Color characteristic**

Character 1: whole color.

Describe in detail: The Chinese-Pinyin 10 key input keyboard's color is mainly composed of gray and white. The ② and ④ district are functional keys, the color of the keys is gray and divide by dark gray lines. The sub interfaces are also made of

**Fig. 4** Dimension design

**Fig. 5** The whole tone of interface

the same color, such as input method switch interface, the menu of characters interface, speech input method interface (Fig. 5).

Characteristic factors: the overall tone–gray, white, blue.

Character 2: color switch.

Describe in detail: When used in app, the send button in district ④ is not available when there is no text input, and the color is gray. When users input text the send key change to blue (Fig. 6a). The keys in district ② and ④ are gray in the unused state, and switch to light gray or white when used (Fig. 6b). The words input keys in district ③ are white, and switch to gray when pressed, and restore when released (Fig. 6c).

Character 3: text color.

Describe in detail: the color of spelling options in the top line in district ① is gray, and the color of selected pinyin is blue. The color of other text are black. The key not available is in gray text.

Characteristic factors: white background with the gray text, white background with the black text, gray background with the black text, gray background with the gray text, blue background with the white text.

(3) **The arrangement of elements**

Describe in detail: all keys are rectangular, the whole interface is even divided into four rows and five columns, most of the key size are equal (Fig. 7a). There are two mainly tone: District ① and ③, located in middle of the whole interface, are text input keys area. The color of these keys is white; District ② and ④, located in two flanks of the whole interface, are functional keys. The color of them is gray (Fig. 7b).

Characteristic factors: keys with rectangular shape, even divided, location characteristics.

**Fig. 6** **a** Color switch 1, **b** color switch 2, **c** color switch 3


**Fig. 7** **a** The whole shape, **b** the two mainly tone

# 4 Explore the Relationship Between Characteristic Factors and Users

Through analysis and summarize above, we arrive at characteristic factors of the input method interface design. Then, from visual perception and touch operation, we will study on what effect these characteristic factors have on the process of human-machine interaction and discuss the availability of Chinese-Pinyin 10 key input method interface. All results of analysis represented by the diagram.

## *4.1 Visual Perception*

In the process of user recognize information from interface, restrict of human's attention is a bottleneck very difficult to overcome. Users search information and find target by glance behavior. Glance behavior reveals the visual search process in detail [11]. Through establish visual search model, the former draws some conclusions about the characteristics of visual scanning. Lots of research in this field reveals many general conclusions, using these general conclusion of visual search can study out how to make it use the least time to get the optimal results, and improve the efficiency.

Then, start with the characteristic factors we extracted, we will establish the connection of the characteristic factors and visual conception, and study how these characteristic factors influence the user access to information using visual search rules.

(1) **The whole tone**

According to the time users perceive application and the importance of application, Alan cooper divide the software into four kinds of status. Every status corresponds to a group of behavioral attributes [12]. Applications in touch screen interface are the same. So for the sake of user's comfort, the whole tone of different interface should be distinct to adjust fixation time and the importance of the application. For instance, application that users often use for a ling time in full screen should in low key and conservative style. The overall tone of this kind of application's interface is black, gray, and white. And application that user only use it temporary is fit for simplicity and bright style. The whole tone of it's interface is blue and bright green [12].

In the Chinese-Pinyin 10 key input method interface, the whole tone is gray and white. When used by users, the interface often used with the chat app. Users need long time to stare at the interface, white and gray as the main color can give a visual experience of quiet and comfortable to user, and reduce fatigued because of long time use.

(2) **Color switch**

A sudden start visual stimulate will attract attention, especially when the stimulation in the peripheral of vision. Because visual system is particularly sensitive to the new perception target [13]. For example, the color of send key from gray to blue, this change will cause the visual attention of users. When users input information in the chat app, the send key is must used. In this case, the change of color can make users more easy to find it.

Chinese-Pinyin 10 key input method use 8 keys include all the letters, so one key present three or four letters. Long press can access the interface shown as Fig. 6b, now the color of the key shift white to blue so that users can know they has access the interface.

(3) **Text color**

The relationship between button color and text color is contrast. Contrast is particularly important in interface design. There are many different method in using of contrast, and all these method are based on color concept. Dark text on white background is most likely to watch, and white text with black background also have obvious contrast. But reading will be more difficult in later situation, because black makes people feel oppressed. From this point of view, it should be less used. Then, similar with black and white, warm color give people the feeling of bulge out from screen and cold color give people the feeling of recessed into screen. So black and the warm colors is more suitable for text and graphics, and the cool colors and white is more suitable for background [12].

Two kinds of color, if they are not in sharp contrast and almost permeates to each other, is not easy to cause user's attention, and even be neglected. Such as the send button in unavailable status, the text color and background color are both gray but in different brightness. Users often unlikely pay attention to this kind of keys at first.

In the interface of Chinese-Pinyin 10 key input method, keys arrangement according to the color contrast is: district ① and ③ in black text with white background, district ② and ④ in black text with gray background, keys in unavailable status with gray text and background. The entire interface in sharp contrast and have a distinction between the important and the lesser one.

(4) **Shape of keys**

A symbol can have many encoding dimension, such as the color can represents a dimension, the size can represents a dimension, and the shape can represents a dimension. With the increase of encoding dimension, search time growth [14].

The interface of Chinese-Pinyin 10 key input method has fewer encoding dimensions. Most of the keys have the same shape and size, each kind of keys have the same color. Fewer encoding dimension can find the target in shorter time.

(5) **Special keys**

There are some features easy to cause visual attention: bigger, brilliant, colorized, transitional (or flashing) [11]. On the interface of input method, there are some special keys in high use frequency, like keys of space, enter, send. A bigger size or more bright color can help reduce the search time.

(6) **The arrangement of elements**

Character 1: arrangement of text.

In the sequence search, each element retrieved one by one [5, 6]. According to the reading habits of human, users find the target from left to right. After input a pinyin, users check out Chinese words by sequence search. The arrangement of the options meet the reading habits can make it easier to use.

Character 2: arrangement of keys.

Function keys arranged on two flanks of the interface. When the users need to use a function key (for example, input emoticons), first they will search target by visual search. Keys in district ② and ④ have the same color and shape, so according to the conclusion of Geisler and Chou, users are likely to use sequence search. And Houry and Clement have discovered, whether the search elements are close in space, there is no much impact [11].

## *4.2 Touch Operation*

Discuss the factors influencing the user's touch operation from two aspects. First is the restrictions of human dimensions. In the interactive process of touch screen interface, size of hand is a limiting factor. A key with a small size will cause the user cannot operate accurately, and a key with large size will make user feel uncomfortable. Second is the state of keys affect user's cognitive of the availability of keys, and then influence the fluency of operation process. In the following, we will analyze the design factors impact users operation process in detail from the two aspects.

## 4.3 The Size of Each Part

(1) Rationality of keys dimension design have effect on accuracy of user's operation. There will form a contact surface when fingers touch screen, so the dimension design of touch screen interface should limited to the contact surface.

When using the virtual keyboard, users touch the screen by thumb and index finger (Fig. 8a). The interface of keyboard is classified as type A, so the upper limit is P95 man of finger size. The contract area of the two fingers touch the screen is $5 \times 5$ mm. If the size of the keys less than this value, there maybe higher probability of misoperation. So the smallest key in the keyboard should larger than this value.

The key size has been measured in preceding, the minimum key size is $5.5 \times 8$ mm, larger than the minimum design size $5 \times 5$ mm. The size design is suitable for most user's finger size.

(2) In the case of one hand operation, user's touch screen by thumb and there is a comfortable operating range. Therefore a touch screen easy to use need to place keys frequently used on this limited area. In Tapworthy-Designing Great iPhone Apps written by Clark [15], it shows the hotspots and bland angle when the right-handed people touch the iPhone screen. He marks the active range of thumb when operated by right hand (Fig. 8b).

In the input method interface, letter keys are used most frequently. In the figure we can see these keys are focus on the hot spot.

## 4.4 Degree of Comfort

The feeling of comfort is mainly from the psychological feeling in the process of interaction, it is an abstract index. In touch screen interface, all function realize on a two-dimensional interface without any physical buttons. The weakening of the sense of touch lead to cognitive uncertainty. An interface with feedback can solve the problem. The feedback itself may has no connection with touch operation, users can also finish touch operation without feedback. But feedback can bring users a greater sense of control. In other words, users can know whether the operation is

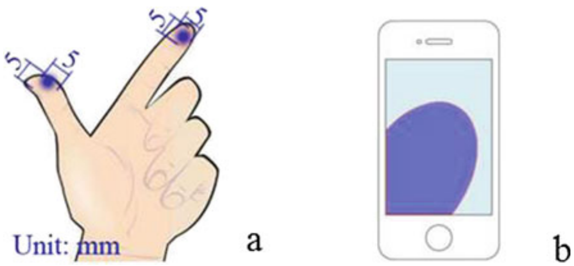


**Fig. 8** **a** The contact area, **b** the active range

successful or not. Users know the machine state for certain will feel the machine more easy to use.

The button color switching brings users feedback in visual, it makes users insure operating results just after operate. And the sound feedback can stimulate the realistic of real physical keyboard.

## 5 The Rules of Touch Screen Interface Design

According to the analysis, we can conclude the general rules of touch screen interface design and each characteristic factors' function in the human-machine interaction (Fig. 9).

The key rules of touch screen interface design:

(1) In the process of touch screen interaction, visual search process mainly influence by color features of elements and arrangement of element;
(2) The brightness of color, the switch of color, different of size. All these characters can be a visual stimulation and cause visual attention;

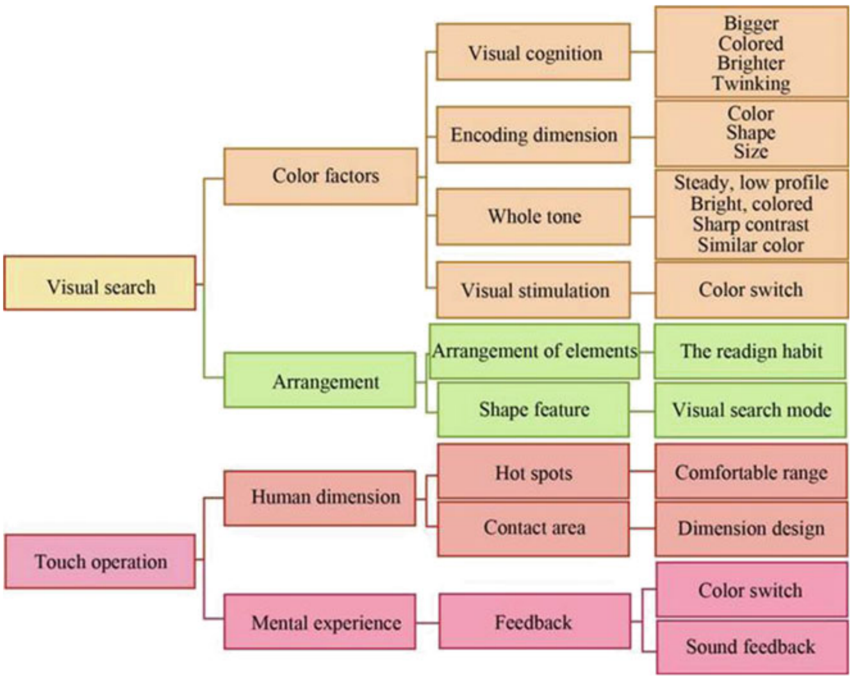


**Fig. 9** The conclusion of characteristic factors

(3) The number of encoding dimension affects the time of visual search, which should be adjusted according to the complexity of the information interface;
(4) Different tone will bring users different feelings, the stander of interface design should be different according to the usage scenario;
(5) The shape and arrangement of elements affects the visual search mode and the search time;
(6) The accuracy rate of touch operation is also relevant to the dimensions of elements;
(7) In order to make touch screen interface more easy to use, feedback is necessary to make users feel certainty in psychological.

## 6 Conclusion

(1) Many characteristic factors like dimension design, color feature, arrangement of elements have influence on the interaction of users and touch screen. Interface meet user's physiological characteristics and habits can have higher ease of use;
(2) Through the study of the two process–visual cognition and touch operation, we concluded the influence of characteristic factors on human-machine interaction by using visual search rules and human dimensions;
(3) To Chinese-Pinyin 10 key input method interface in iPhone in iOS9.2 system as an example, how each factor affects the user's visual perception and touch operation process is studied. And the general rules of touch screen interface design are included. Finally the availability of the keyboard is verified.

The study of this paper give an example of study about the connection of characteristic factors and human-machine interaction. More study about the design factors and design rules can carried out following this way.

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# The Contribute of Graphic Style and Connotations to Memorability of Brand Marks from Agri-Food Sector

**Daniel Raposo, João Neves, José Silva and Catarina Laginha**

**Abstract** This study aims to understand the process of decoding brand marks particularly how people perceive brand marks styles and connotations, and also reveal which characteristics contribute a better memorization. It is not intended to create standards or a system for brands to employ during brand marks design or visual identity projects. Our purpose is to provide knowledge, a reference frame and principles according to which companies can make informed decisions about how to evaluate or design brand marks. The study was conducted online with 150 respondents in Portugal, asking them to evaluate 15 brands marks of agri-food sector, specifically, olive oil brands. It was used a model adapted from the C-HIP model (Wogalter et al. in Warnings and risk communication. Taylor & Francis, London, 1999 [1]) particularly for meaning/comprehension; Subjective evaluations; Self-reports. The respondents were asked to name the brands they found to be the most memorable and visually appealing, selecting the top attributes recognizable and those they did not recognize. The brand marks were organized by typologies, iconographic, descriptive or abstracts, establishing relations with graphic style, connotations and memorability.

Brand marks: The graphic sign, the 'mark' or 'marque' that identifies the brand. Also known as the logotype and/or the symbol.

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## 1 Introduction

There is broad consensus on how the brand visual identity plays an important role in the differentiation of companies, products and services. This belief seems to recognize the importance of the visual language, its narrative and graphic rhetoric in mediating the communication at a distance between the company and its audiences.

The globalized market seems to have enabled the emergence of similar products, along with an increase in the valuation of services and an apparent rise in the value of the brand visual identity by people. In this scenario of a more global and increasingly digital market, the brand image and its reputation can become more important than the tangible assets of the company. In fact, distance communication and particularly the Internet enable a small business to be perceived as a large organization, whereas markets are broader and complex.

The visual language is used daily to get to know, differentiate and present products before different audiences.

It is important to note that the repertoire of signs of the visual language is almost limitless and that they don't have one univocal meaning, once the semantic meaning varies with the shape, the expression, culture and context of use [2].

In the case of the visual language, it is likely that the denotative meaning, this is, the most direct, common and obvious, to be a less frequent recourse compared to the connotative, a secondary association or figurative meaning.

Accordingly to Acaso [2] the visual language "is the oldest semi-structured communication system we know (…) the one that has the most universal character", nonetheless its semantic meaning changes considerably with the culture.

Traditional marketing research seems to be limited to the identification and description of the predominant graphic features or those that are more contrasting in a given market, offering few results about the culture and how it affects the meaning of graphic signs. On the other hand, as already reported by Simonson et al. [3], in the last four decades the scientific community has shown an increasing interest in the study of the cognitive and perception processes and in subjective judgments and decisions.

Without belittling the importance of the studies conducted, it is considered relevant to point out the lack of research conducted from the perspective of design. The research developed from the perspective of Marketing and Psychology were essential for knowledge, but are still missing specific studies on the contribution of design, selection and semantic links between the graphic signs (logo, symbol, label, packaging and advertising and its graphic characteristics) and how they are understood and how they generate different notions of value.

## 2 Conceptual Framework and Hypotheses for Graphic Style and Connotations Influences to Memorability of Brand Marks

As stated by Conzola and Wogalter [4] the first graphical model to represent the communication process was presented by Harold Lasswel (1948) and was subdivided into the following vectors—Who, What, How, To Whom. Other authors affirmed that the first model was "The Mathematical Theory of Communication" presented in a paper in 1948 by Claude Shannon and Warren Weaver and republished in 1949 in a book were they explained their model of the communication system, crossing technical questions, the semantic process and the measurement of the effectiveness of the transmitted message.

Over the years, these models were the basis for subsequent studies and were adjusted by several authors, notably by Charles Morris in 1946, who proposed a work methodology based on three levels, Semantic, Syntactic and Pragmatic [4].

Based on the communication models mentioned above the authors Wogalter et al. [1] established the Communications–Human Information Processing (C–HIP). The same model was explained in a paper written by Conzola and Wogalter [4], where they describe how the information is articulated in stages dependent on people's perception, involving the attention, the understanding, attitudes and beliefs and motivation or interest. On the other hand, the audience perception influences their behaviour depending on the message meaning (Fig. 1).

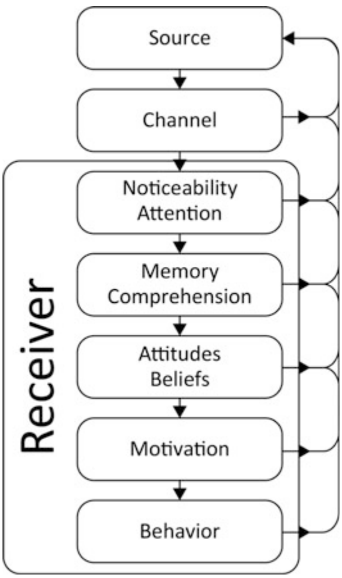


**Fig. 1** Communication–human information processing (C–HIP) model (Adapted from [4], p. 312)

Nevertheless their differences, the different models of communication coincide into establish a communication dependence on a repertoire of inter-subjective signs organized by a common code.

The full repertory of signs shared by emitter and receiver during the communication process is only possible by a number of more or less shared signs, and more or less understood by the same way.

This concept is not contradictory to the effectiveness of communication design, but it demonstrates the complexity of the process and the importance of the designer as author, as a mediator or agent in a society that communicates. But the effectiveness of graphic design implies the creation of messages with strategic sense. According to Frascara (p. 78) [5] "it's important to know the visual language of the target audience. Choosing the right aesthetic approach, in relation to the message meaning and with the culture of the receiving audience, is crucial for the message effectiveness, given its relationship with the emotional reaction of the public."

Similarly, Frascara (pp. 23 and 82) [6] explains how "the visual communication design deals with the design of visual messages, in order to affect knowledge, attitudes and behaviour of people" and for that reason it focuses on human communication and less in the message. And for that reason the design process is centred particularly on human communication and less in the message by itself.

The designer must respond effectively to the company requirements and ensures that the message is relevant to people needs.

As Frascara (pp. 23 and 31) [5] writes "design is to coordinate a long list of human and technical factors, transforming what is invisible into the visible, and communicate" (…) "the designer designs essentially an event, an event in which the public interacts with the design and produce communication. Therefore, the goal of the visual communication designer is the design of communicational events".

This study is based on the C-HIP model adapting it into the communication process resulting from the Brand Visual Identity, allowing us to define the "Triad of the Creation of Meaning during Communication" (Fig. 2).

The "Triad of the Creation of Meaning during Communication" is divided into the dimensions of Semantic, Syntactic and Pragmatic, which are related, by the same order, with the Brand Identity (BI), Brand Visual Identity (BVI) and Brand Image (BI).

First, the BI which includes the personality, the culture and the brand values, being related with the semantic in terms of brand symbolism, since its coding until its decoding [7].

After that, the BVI which regards the selection and coding of graphic signs (by design), is related to the syntactic, that is, how the infrastructure signs create a shape and an expression or the global graphic style capable to trigger connotations, the attention and guide the perception/recognition.

As stated by Frascara (p. 69) [5], "the communication begins with the perception". Therefore, the BI is the decoding process or the creation of meaning in the mind of the target audience, which culminates with the comprehension. Depending on the value that the meaning receives, on it's connection degree with the ideals of the person as well as the fascination power created by the graphic sign (in a

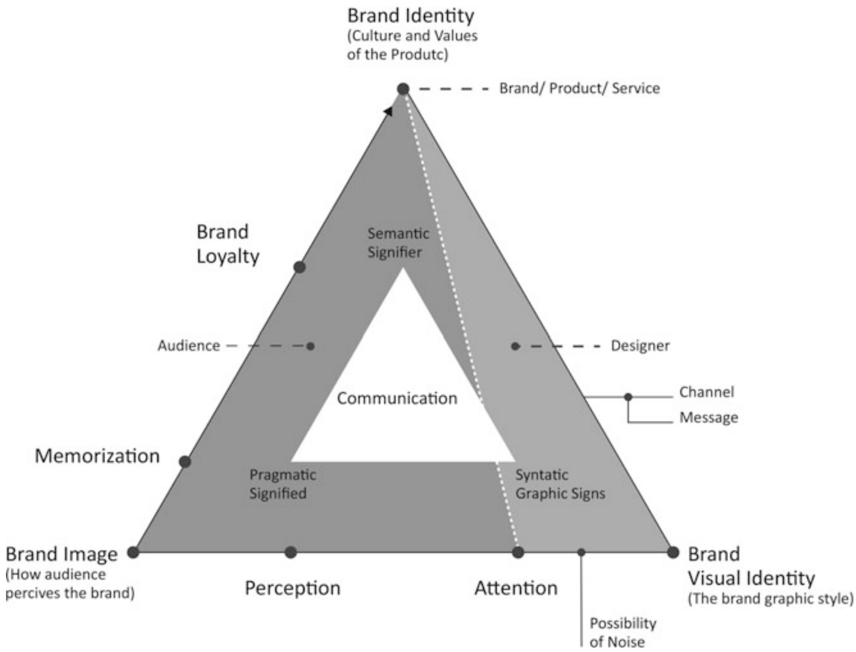


**Fig. 2** Triad of the creation of meaning during communication (Authors 2016)

denotative and connotative level), there may be a change in people's behaviour, such as buying of a product, or even the establishment of an emotional bond with the brand (brand loyalty), corresponding to the feedback.

Consequently, brands are systems created artificially to become a natural and human phenomenon. In fact, brands only exist when they become public, this is, when they are perceived, comprehended and valued by its recipients [8].

At the level of syntactic, is developed the design of graphic signs and supports of visual communication, considered necessary during the initial program. This process is divided into the same three phases: semantic, syntactic and pragmatic. Being that the syntactic requires considerations in terms of composition, shape, color, typography, and also a set of implicit processes for design validation by the public through questionnaires or tests about the comprehension, memory or perception, etc.

So, the design of the Brand Visual Identity requires relating the dimensions of semantics, syntactic and pragmatic, since they are implied in an articulated structure, wherein the results obtained in each stage generate useful data to the following, and they all influence each other.

## 3 Review and Synthesis of Existing Research on Graphic Style and Connotations of Brand Marks

One of the first studies on the graphic perception was conducted in 1911 by Burt [9] invited by the British Association for the Advancement of Science—BAAS.

The study involved the analysis of the effects of different fonts in children's books, particularly as graphic typography style influences the readability and comprehension of a message. These studies were published in a paper in 1955 in partnership with Miss J.L. Martin and Mr. W.F. Cooper in the British Journal of Statistical Psychology, VIII, pt. I, pp. 29–57 and in 1959 in the book "The psychological study of typography."

Based on the observation and analysis of advertising, Farrar [10] defined eight types of style or tone of voice to use in advertising, which requires the correct font selection. Also from an empirical perspective as a designer in 1940, Frederic W. Goudy wrote the book "typology" which inquired about the ability of the font to impart personality, power and direction to messages.

Osgood et al. [11] have proposed the Semantic differential scale in 1957, which has often been used in subsequent research. This method consists in a seven-point scale to identify and measure bipolar adjectives that correspond to the connotative meaning, divided in three general dimensions: evaluation, potency and activity.

Also in 1977 was published the book "The company image: Integrated communication methods" where Joan Costa explained how to create a system from the verbal and graphical signs, products, services, interior and communication design, according to the desired brand image [12].

In 1979 Blanchard [13] defended his doctoral thesis at the Sorbonne entitled "For a Semiology of typography" (directed by Roland Barthes), later extended to the book "The Letter" (1988) where he talks about the type-graphics well as speech logo Semiotics and finally published "Help to choose typography" (1998), which contains data on typo-graphical connotations.

Haig [14] began the study about the semantics of brand marks in 1979, which was expanded with Harper collaboration [15]. Although their studies are dedicated to the articulation between denotation and identity, they are especially concerned to the symbol and less to the logotype and corporate typography.

Henderson and Cote [16] showed how brand marks have a crucial role in the communication of the brand's they stand for. Were also Henderson and Cote [16] who developed researches to help designers during selection or modification of brand marks, to achieve corporate goals and based on empirical analysis of 195 Brand marks grouped in 13 different categories organized by shape. In 2004 was developed another study from them with Joan Giese.

In 2002 Childers and Jass [17] have examined the semantic nature of typography, its influence on advertising and consumer perception.

In addition, Pimentel and Heckler conducted a study in 2003, divided into stages, to evaluate the reactions of the audience to redesign on brand marks, from restyling to integral redesign, more or less familiar, more or less acceptable. The study is a continuation of the doctoral thesis Pimentel (1997) and to a previous article with Heckler (1999) also about the consumer perception about the brand marks design [18].

The contribution of Thangaraj [19] consisted on a literature review and a brief reflection about the conducted studies concerning to the connotations of the letters, which concludes with the need for a new scientific and credible study.

The researchers Henderson, Giese and Cote (2004) conducted an empirical study that aims to help during the management of the typographical connotations according to its graphic characteristics. With reference to this research, in 2006 Doyle and Bottomley [20] have conducted another study that seeks to relate the meaning of the brand marks with the company or product attributes.

From the perspective of design, Iñurritegui [21] defended his doctoral thesis on “Analysis of meanings resulting from the design and style of the type-icon-graphics signs in the Corporate Visual Identity system, which aims to demonstrate empirically that the signs of visual identity depend on their connotations”.

From the perspective of psychology, Boncompte [22] developed his thesis “the perception of typographic style during the formation of the Corporate Visual Identity,” which is based on typography as an advertising resource, experimenting with a sample of 100 respondents and the advertisements of five brands. The study of this author states that typographic styles are: serif, sans serif and calligraphic, and seeks to detect associations between each kind of typeface and the respective audience, positioning and market.

The doctoral thesis Sousa [23] with the theme “Portuguese Brands: A methodology for the affirmation and evaluation its impacts”, a proposal for brand evaluation, based on direct application of methods “Constellation attributes” (Abraham moles 1990) and “semantic differential” (Charles Osgood 1957) to four Portuguese brands.

In the same year António Lacerda’s thesis [24], “Design and Identity management: Brand marks and Corporate Image”, which deals with the development of a model to audit the Corporate Image, experimented on brands of Portuguese universities.

Raposo [8] presented his doctoral thesis “The letter as a sign of corporate visual identity: encoding and decoding of the identity system.” This thesis aims to understand the process of encoding and decoding of typographic signs in Corporate Visual Identity, identifying connotations. To do this, the research is based on the case study of 15 brands, confronting the designer’s intent (encoding) and the corporate strategy with audience perceptions (decoding).

Finally, the study of Oliveira and Alcobia [25] has shown that certain visual and material characteristics of primary packaging, from agri-food products, can change preconceptions on the product quality.

# 4 Methodology

In order to study the communication process resulting from the Visual Brand Identity, we selected a non-interventionist approach, based on descriptive cases study. According to Yin [26], cases study is a method suitable for research about a contemporary phenomenon within its real-life context; when the boundaries between phenomenon and context are not clearly evident; and in which multiple sources of evidence are used allowing the researcher to go beyond the quantitative or statistical results into the understanding of the behavioural conditions through the actor's perspective.

The case study were related to 15 Portuguese brand olive oil, from the the country's central region, provided by their industry associations "Inovcluster—Associação do Cluster Agroindustrial do Centro" and APABI—Associação de Produtores de Azeite da Beira Interior. Among these 15 brands, four of them are certified DOP—"Denomination of Protected Origin" and three are "Certified Organic", while the others correspond to current products. In total were surveyed 150 Portuguese's, using a questionnaire made in Google Forms. The respondents were olive oil consumers, with ages stratified into the following age groups: 18–25, 26–35, 36–45, 46–56, 57–65 and >66.

## *4.1 Study 1—Perception and Comprehension of Brand Visual Identity*

The second study is a survey conducted online to 75 Portuguese olive oil consumers, in order to know their perception, comprehension and the connotations created by brand marks. The Brand marks were presented with a visually equal size.

The questionnaire was organized into five parts: the first in which Brand marks were shown the out of their context, asking respondents to indicate the food product typology: Wine; Olive oil; Juice; or Oil.

In the second part, the questions were made considering the use of the brand mark on a label in the bottle and the product (primary packaging). In order to avoid a possible sequence effect, the images were presented in random order.

In this second part respondents were asked to indicate whether to buy each product.

After that, during the third part, respondents have established associations with the apparent price of each product: Low Price; Average price; High Price.

Consequently, at the fourth part, respondents indicated their perception of value: Poor quality; Medium Quality; Good quality; Excellent quality.

Finally, during the fifth part of the questionnaire, respondents indicated their perception of the product considering three bipolar scales: Conservative—Modern; Rustic—Technology; Luxurious—Banal.

**Table 1** Summary of results in study 1 about Brand marks formed by symbol and logotype

| Brand Mark | FIDORE Azeite Cova da Beira | Estacal | [illegible] | [illegible] | PICOTO | QUINTA DA CALDEIRINHA | portas de rodão | AVÔ PIRES |
|---|---|---|---|---|---|---|---|---|
| Olive oil | 62,7% | 53,3% | 88% | 48% | 20% | 6,7% | 72% | 93,9% |
| Wine | 13,3% | 33,3% | 4% | 14,7% | 72% | 88% | 18,7% | 6,7% |
| Oil | 24% | 13.3% | 8% | 30,7% | 6,7% | 1,3% | 9,3% | ---- |
| Juice | ---- | ---- | ---- | 6,7% | 1,3% | 4% | ---- | ---- |
| **Buy Intention** | | | | | | | | |
| Yes | 78,7% | 77,3% | 41,3% | 30,7% | 49,3% | 44% | 81,3% | 48% |
| No | 21,3% | 22,7% | 58,7% | 69,3% | 50,7% | 56% | 18,7% | 52% |
| **Price Rating** | | | | | | | | |
| Low | 16% | 32% | 49,3% | 69,3% | 25,3% | 29,3% | 12% | 22,7% |
| Medium | 37,3% | 60% | 34,7% | 28% | 20% | 49,3% | 68% | 44% |
| High | 46,7% | 8% | 16% | 2,7% | 74,7% | 21,3% | 20% | 33,3% |
| **Quality Rating** | | | | | | | | |
| Poor | 2,7% | 8% | 17,3% | 28% | 6,7% | 29,3% | 2,7% | 9,3% |
| Medium | 30,7% | 54,7% | 56% | 58,7% | 22,7% | 29,3% | 44% | 33,3% |
| Good | 36% | 30,7% | 18,7% | 12% | 29,3% | 36% | 38,7% | 46,7% |
| Excellent | 30,7% | 6,7% | 8% | 1% | 41,3% | 5,3% | 14,7% | 10,7% |
| **Classification Concept** | | | | | | | | |
| Conservative | 9,3% | 33,3% | 18,7% | 21,3% | 14,7% | 20% | 8% | 40% |
| Modern | 33,3% | 14,7% | 10,7% | 4% | 16% | 22,7% | 36% | 8% |
| Rustic | 4% | 13,3% | 10,7% | 21,3% | 5,3% | 4% | 8% | 42,7% |
| Technology | 2,7% | 6,7% | 8% | 2,7% | 8% | 5,3% | 9,3% | ---- |
| Luxurious | 29,3% | 4% | 5,3% | ---- | 49,3% | 5,3% | 5,3% | 4% |
| Banal | 21,3% | 28% | 46,7% | 50,7% | 6,7% | 20% | 33,3% | 5,3% |

According to the administrative regions of Portugal (NUTS II) respondents are distributed as follows: the Central Region had the highest number with 57.3 %, followed by 22.7 % with Algarve and Lisbon Metropolitan Area with 13.3 %.

Still, 57.3 % of respondents were female and aged between 18 and 25 was predominant, corresponding to 48 % of the total, followed by 36–45 with 24 %, and 46–56 with 16 % (Tables 1, 2).

## 4.2 Study 2—Brand Marks According to Attention and Memorization

The third study is a survey conducted online to a second sample of 75 Portuguese olive oil consumers, in order to test the attention and memorization of brand marks.

The questionnaire was organized into three parts: the first in which the panel with Brand marks was viewed during 1 min. This panel contained only the Brand

**Table 2** Summary of results in study 1 about Brand marks formed by logotypes

| Brand Mark | TERRAS D'ACHA | fio | Olibeiras | QUINTA DA TAPADA NOVA | monforte da beira | Casa dos Poços | Ethos |
|---|---|---|---|---|---|---|---|
| Olive oil | 18,7% | 80% | 78,7% | 12% | 41,3% | 64% | 49,3% |
| Wine | 70,7% | 12% | 4% | 86,7% | 42,7% | 32% | 25,3% |
| Oil | 6,7% | 4% | 17,3% | 1,3% | 13,3% | 4% | 25,3% |
| Juice | 4% | 4% | ---- | ---- | 2,7% | ---- | ---- |
| Buy Intention | | | | | | | |
| Yes | 56% | 76% | 60% | 50,7% | 90,7% | 85,3% | 60% |
| No | 44% | 24% | 40% | 49,3% | 9,3% | 14,7% | 40% |
| Price Rating | | | | | | | |
| Low | 12% | 13,3% | 56% | 30,7% | 16% | 12% | 12% |
| Medium | 42,7% | 48% | 37,3% | 57,3% | 61,3% | 46,7% | 29,3% |
| High | 45,3% | 38,7% | 6,7% | 12% | 22,7% | 41,3% | 58,7% |
| Quality Rating | | | | | | | |
| Poor | 10,7% | 4% | 17,3% | 16% | 4% | 8% | 8% |
| Medium | 32% | 33,3% | 46,7% | 56% | 33,3% | 26,7% | 34,7% |
| Good | 40% | 48% | 33,3% | 24% | 46,7% | 46,7% | 44% |
| Excellent | 17,3% | 14,7% | 2,7% | 4% | 16% | 18,7% | 20% |
| Classification Concept | | | | | | | |
| Conservative | 8% | 14,7% | 14,7% | 24% | 18,7% | 9,3% | 10,7% |
| Modern | 46,7% | 42,7% | 9,3% | 21,3% | 36% | 53,3% | 28% |
| Rustic | 1,3% | 5,3% | 13,3% | 14,7% | 6,7% | 5,3% | 12% |
| Technology | 10,7% | 9,3% | 6,7% | 1,3% | 6,7% | 4% | 8% |
| Luxurious | 10,7% | 10,7% | 2,7% | 1,3% | 6,7% | 16% | 25,3% |
| Banal | 22,7% | 17,3% | 53,3% | 37,3% | 25,3% | 12% | 33,3% |

marks evaluated during the study 2, which is why it was chosen for a second sample of people to inquire. The Brand marks were presented with a visually equal size.

Following by a second section to the brand marks during which subjects completed 4 popular sayings, a task only used to eliminate effects, which may be attributed to short-term memory [17].

Finally, at the third section, the selected 15 Brand marks were mixed with ten other Portuguese olive oil Brand marks.

The subjects were asked to identify the Brand marks they saw in the first brand mark board, at the questionnaire first part.

Organized by the administrative regions of Portugal (NUTS II) respondents are distributed as follows: the Central Region had the highest number with 60 %, followed by 16 % from North Region and Lisbon Metropolitan Area with 12 %.

**Table 3** Summary of results in study 2 about memorization of Brand marks

| | FIDORE | Estacal | [illegible] | [illegible] | PICOTO | QUINTA DA CALDEIRINHA | portas de rodão | AVÓ PIRES |
|---|---|---|---|---|---|---|---|---|
| Memorization | 58,7% | 32% | 38,7% | 45,3% | 46,7% | 40% | 70,7% | 73,3% |
| | TERRAS D'ACHA | [illegible] | Olibeiras | QUINTA TAPADA NOVA | monforte da beira | Casa dos Poças | Ethos | |
| Memorization | 70,7% | 73,3% | 72% | 74,7% | 48% | 42,7% | 70,7% | |

Also, 58.7 % of respondents were female and aged between 18 and 25 was predominant, corresponding to 41.3 % of the total, followed by 26–35 with 33.3 %, following the 36–45 with 20 % (Table 3).

## 5 General Discussion and Conclusions

The results of the first questionnaire show that the Brand marks with symbols, particularly the most iconic, were the most associated with the olive oil than those composed only by the logotypes. However, the results of "Brand mark" of Picoto show that the use of heraldic language is more related with wine than olive oil.

The study also demonstrate how the color reinforces the meaning of the name, the symbol or logotype. Can be observed as the logotypes using mainly yellow or gold were more associated with olive oil than those in black, although by itself the color is not enough to define the meaning.

In addition, the data point that the brand name influences the perception, as exemplify "Quinta da Caldeirinha", "Terras D'Acha", "Monforte da Beira", two names of farms and a location. Likewise "Picoto" they were associated to wine products. Nevertheless, This data is also related to the use of Classicals typefaces in Uppercase.

The geometry of the upper case comes from "Roman Capitalis Monumentalis" and together with the name of a farm or a coat of arms has connotations as austerity, excellence, luxury and nobility.

Furthermore, it can be pointed out how a change from Classicals into Lineal, Glyphic or Mechanistic typefaces triggers associations with casual or modernity, a moderate quality and price.

The number of case studies does not allow us to draw conclusions generalizable about it, but the data indicate that the Brand marks in which there overlap among logotype and symbol appear to have lower quality and low price.

The products of Estacal, Probeira, Portas de Ródão and Quinta da Tapada Nova have a very similar bottle and all were considered medium in terms of quality and price rating but in contrast they were associated with very different adjectives. We believe that this change in perception was caused by the label and the Brand mark.

Fidore and Olibeiras are two other examples in the use of a similar bottle but which contrast in graphic style and therefore get opposite results in terms of price, perceived quality and adjective (modern vs. banal).

In the first questionnaire was an open question where respondents were asked to explain their choices. Most pointed to buy olive oil with low or medium cost and that was why they chose to buy products that they seemed affordable. The subjects also establish relationships between overlapping elements, poorly designed drawings or very detailed with amateurism products.

Furthermore, they pointed that the bottles used by "Avô Pires" and "Ethos" resemble Oporto wine and that "Avô Pires" seems to be a water Brand mark in a oil bottle.

It is with some surprise that we observed that the data from the memory test indicates that the logotypes Brand marks obtained higher percentages, above to 70 %, with two exceptions. However, "Monforte da Beira" is the only logotype that doesn't have it's specific graphics features. It's the name displayed in a Linear typography, without no more intervention beyond the size and alignment.

"Casa dos Poços" also records lower results because of it's graphic complexity and because the group has poor contrast or visual weight.

This study did not enable us also to confirm all results of Oliveira and Alcobia [25] regarding the shape of the packaging. However, the two studies showed that consumers are influenced by Brand Visual Identity and and how the graphic signs are interconnected in creation of meaning.

Tis study shows how each graphic sign generates its own connotative meaning, this is to say that each decision during design process has consequences in he audience perception. It was possible to see that Brand marks can establish associations with product types, but they operate in a given context and function better when are coordinated with other signs as the label and the primary packaging.

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# Production Design and Game Design in Videogames: Action, Emotion and Immersion in the Player Lived

**Carlos Figueiredo**

**Abstract** In a linear narrative of a 3D animation the viewer is led, without choice, through a number of spaces, events, conclusions, expectations, premonitions, anticipations, fears, joys, empathy and dislikes, characters and environments, fictional readings in dreamlike narratives, where reality and fantasy that tend to blend. Across this experience of fiction—perceived, understood, felt and judged—an animation viewer does not have, without being aware of it, any possibility of free will, because after all he is being driven to feel and watch a story that is narrated from inside, along its multiple steps. Differently, in a Videogame the Player is allowed to act on the plot's fictional world, in its characters and events. In this tale storytelling and script, the referred linearity would become here in theoretically infinite lines of possible events and plots, with diverse endings, in which a narrative story line diverges in multiple plots. Or is it not so?

**Keywords** Videogames · Player · Fictional living · Interaction · Plot storytelling · Production design · Game design

## 1 Introduction

This study deals with games in which the relationship between gameplay, narrative and fictional worlds implies a storyline and plot where the player can go through the fictional space immersive way and that this and the plot are inseparable from the narrative. This study is devoted therefore to Games that are simultaneously Role Play Games and First Person Games.

In these Games, strongly than in other categories, the Player as a lived experience of the Game's tale and its unfold, having readings and feelings from a

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dreamlike narrative, where reality and fantasy tend to blend and the Player tend to feel that for a time he did exist on that fiction and was, as an inhabitant and an acting character, a factor that did changed the tale and its outcome itself.

## 2 The Player Experience of a Game with the Linear Narrative of 3D Animation Movies

There are two forms of experiential living in a world and of narrative: a linear one-sided telling of the animation movies, or the same capacity of this spectator that feel inside a fictional world, but with the ability of moving, look and act upon that world's space, objects and character, so being a part of it.

In the part of a Game narrative that uses the first approach, the player, like a spectator, is being driven to feel and watch the story that is narrated to him from inside the fiction, but as an animation movie viewer he does not have, and he is not quite aware of it, any chance of free will in is living of the fictional play. In this case the viewer's reading, emotion and sense of fictional world, tale, and is plot is led and driven, without any choice.

### *2.1 Seeing and Reading the World and Their Events Through the Camera Windowed Eyes*

The camera—the eyes of the spectator or player—is the element that in a linear narrative cinematic can select what is seen and how is seen, conditioning the spatial concept, identity and characteristics of the fictional world and the telling of events of the fiction. Its role is preponderant in the translation of the drama by the telling.

In the cinematic scope, the camera is responsible for visually describe the characters and show their relationships, moods, character and intentions [1]. It will cause and condition the emotional and affective responses of the viewer/player, building the desired narrative reading of the fiction.

In the linear narrative of an animated film there are two levels: the sense of the script or argument and the narration of the story of places of the world of fiction; their past, identity, the people that inhabit them.

A game will add up a third form of narrative; emerging, the interaction with the universe, individual to each player.

In the cinematic linear narrative approach, used in sections of a game, the portions of space that the camera reveals in the frame and its editing are determined not by the observer, but by the agents who assembles the dramatic narrative visual and of action. These determine in absolute the perception of the fictional space and what it contains, manipulating the emotional and perceptual experience of the viewer/player.

Through the lines of action and continuity of action and movement, and placing the camera over several shots of an assembly, and also looking off-screen announcing another space, it is possible to create a notion of a fictional space in the player through in a three-dimensional oriented mindset, creating in the player a "synthetic space." This is independent of the reality of the depicted space.

The referred notion by the player as center of a fictional world that surrounds him turns in a very strong device of immersion in the fictional space and world. This is used in movies as in games, and make the viewer/gamer feel to belong and be at the world of the fiction and in its living story.

The immersion effect also occurs when you narrow the division between the real self of the player and his avatar in a game. When this take place the events that happens to the avatar (the character) become significant as if they were happening to the player himself [2].

Immersion may occur at different levels. Zangalo refers two: physical and cognitive-emotional. Immersion involves a "sense of presence." [3] considers physical immersion when the individual is physically surrounded by experience.

The cognitive-emotional level described by Zangalo constitutes the emotional involvement of the player or viewer with fiction. This is where is based the phenomenon of "suspension of disbelief" [4], that is when the player or viewer accepts the premises of fiction to be true. The player then accepts fiction as reality by getting involved and becoming immersed in that fictional universe.

### 2.2 *Fictional World: Spaces, Events, Characters and Environments*

The Production Design, infers and materialize from the Script and the Game Design, with the Concept Art, the creation of the Fictional Universe—its spaces, characters, props ambiences. This world is prepared to host the fictional plot and the narrative, as the player himself [5].

This fictional world must create a visual and experiential identity, comprising cultural and social urban or natural space, humanized and not: the architecture, objects and props that make those spaces fit to live in, the definition of the characters that inhabit that world. These characters and actions that will occur there have to make in the viewer a sense of coherence, authenticity, credibility, immersion and identity.

This fictional space must be scenic too. It must also create an atmosphere and state of mind that is according to the fiction in every scene and the concrete actions que will take place at every moment.

The most significant devices for the creation of these ambiences mostly corresponds to a symbolic dimension: "The atmospheric qualities of sets, places and environments are essential in establishing a mood and the deployment of an emotional feeling about the world around the movie" [5].

It is fundamental to equate visual metaphors such as the symbolism of color and light-shade, of power, monumentality, religion, the fantastic or mystical, ways of life, period and historical culture, romance, technology, society, styles and architectural poetics, the purpose of architecture, whether civil, military, religious, political and status of the owners of these spaces and buildings.

The scenic space is intrinsically connected with the characters that inhabit in it and interact, as well as with action and narrative that happens there: "the characters, events and architecture interact and designate each other" [6]. The scenic space has also an emotional component, it places the viewer in a context from the reading he makes [7].

### 2.3 Feel and Emotion

The lighting, for their symbolic and emotional attributes, is a key aspect in creating an appropriate perceptual and dramatic vision of the cinematic narrative. When in historical narratives, often lighting style draws influences from art of the period, such as paintings [8].

Light and Color have deep roots and meanings in us: the blue that gives tranquility, related to the metaphysical (heaven) and with mystery and dream (sea), the Green and Brown, who have a land-based connotation, referring to the earth (ground, rock, vegetation). Lighting outside a familiar context can refer to a sense of unease, distrust or fear.

The events of a game have to provoke emotion [2], as this is an essential aspect that captures and involves the player in a game. Generated emotions are one of the motivations to keep immersed and committed a player in the development of a game.

There are some emotional triggers [2] that are used to generate emotional responses: learning new information, development and internal growth of the characters, challenges, threats, social interactions, purchases, music, spectacle beauty, environments, just to name the most common.

Not only the quality of light is relevant, but also the shadows that it creates. Shadows in a space and its representation also establish spatial relationships and depth between objects. Without them the location of an object in relation to a surface is not perceptible—we do not know if it is or not on that surface, nor the relative distance [9].

The placement of the key light in relation to the camera and to the subject has a strong contribution to the illusion of depth and three-dimensionality, in particular if it is placed in a different alignment than the axis of the camera [10]. The contrast between bright areas and shadow ones allows to highlight the three-dimensional nature of objects and spaces, giving a greater or lesser depth to space revealed in the image and in the shot. Bright objects against a more dimmed background pick up the viewer's attention to this portion of the frame or object. This creates a changeable sense of depth as lighting differences originate at different depths enhances contrast and separation between them.

## 3 Player as a Character of a Plot and World

In a Videogame the player is allowed to act on the plot's fictional world, characters and events, having also an experience about the fictional world and plot, from a centered and immersed point of view, in relation to the Fictional World and Story that unfolds there.

Things are perceived, understood, felt and judged by the player also according to the fictional world, its space, objects and characters feedback to the player's action.

In a Game, the tale storytelling and script also becomes theoretically an infinite number of lines of possible events and plots: infinite possible diverse ends? Narrative story lines diverges then in multiple plots, so Production Design has to transform the animation movie script in controlled parallel plots, according to skill script and Game Design approaches.

These must allow the player to be able to live, observe, feel, act and to be acted as living and existing in the intended videogame fictional story and drama, and act on its fictional world—so collaborating in its creation.

One aspect that distinguishes videogames from other entertainment media is the interactivity and the ability for the player to intervene directly on events, shaping and conditioning the narrative. This "freedom" appeals much to the player as also allows him a greater immersion in the game world, because it facilitates the projection of his imagination about this world and the events that he himself casts [12].

But despite the game's designer does not have full control of everything the player does—there are narratives and emergent gameplay. So there must be some control and structure in the interactive narratives. In order to maintain a sense of freedom in the game, this control is done in a subtle and indirect way through various forms, called "indirect control" of the player, such as constraints, objectives, interfaces, visual design, characters and music [12].

### *3.1 Player Action Upon a Game Plot and World*

The space is a "shell" where the individuals lives. In the case of a fictional space, it is where characters inhabit. The space fence surrounds and supports everything the character does and is. They are thus inseparable. You cannot remove the mark of a person's life out of his space—the context—where he exists and lives. It is therefore necessary to take into account the psychology and behavior of those who want to convince that live and belong to a space, a place.

The different places talk about the characters and their evolution throughout the narrative: its status, tastes, habits, expectations, attitude, mood, lifestyle, personality, in short, the experiential dimension of the inhabitants of their world.

The space is also not separable action, since that action happens and makes sense in it. Space is the support for action be able to happen. It also defines and configures the action. It might be said that a particular space and its characters determine and limit the possible actions in this.

There are many aspects that shape the form, mood and emotions related to a space, such as:

– Color contrasts: hot and saturated colors advance; cool colors and de-saturated recede
– Light contrasts: lighter areas advance; dark areas recede
– Side lighting/oblique/away from the camera axis
– Aerial Perspective (fog)
– Light, shadows and reflections
– The apparent size and proximity between objects
– Convergence of strength lines (perspective)
– Rhythm and repetition of elements that decrease in depth
– Overlap between elements

## *3.2 Fictional World Limits and Constrains*

The key mechanisms of a Game are the ones that produce *Gameplay* or playability. They determine the procedures and rules of the game, as well as its objective, the conditions to achieve the plot's goals, and the consequences of achieving them or not.

The essence of the gameplay is based on the relationship between the challenges that the player has to overcome and their own actions, that will allow him to overcome that challenges. This concept must take into account the importance of "the subjective experience that emerges from the interaction between game and player" [11].

It defines the challenges that the game offers, such as the player's actions to address these, and also the effects of their actions on the fictional world of the game. These are the mechanics that generate the game events the player interacts with [2].

Are fundamental mechanics: rules, objectives, challenges, obstacles, and the consequences and rewards dependent on the player's actions.

There are also Space Constrains and Limits, as space cannot be, in the game reality, infinite as the concept given to the player suggests.

Space is one of the circumstances that determines the intervention of the player: therefore, both limits and obstacles are constraints to the player navigation and action. Sometimes obstacles and boundaries are blended, because they are elements that delimit the game world area, as well as they prevent the player to transpose them. So the limits are also, after all, obstacles to the player's progression.

These constraints are called edge metaphors: they are a perceptually logical reason why the player cannot go beyond certain limits of the space in these fictional world. They are created seemingly natural constraints, embedded in the very morphology or built space elements—such as ground or walls and buildings that delimit an area—to avoid destroying the notion of an infinite fictional world where the tale and plot of the game take place.

Obstacles are factors that influence the action of the player, in relation to the dramatic action and progression of the gameplay. They involve all the various opposing forces (opponents), or elements which hinder the action of the player, such as puzzles or quiz devices, objects or other that impose a constraint to the movement or to the player progression through space. In the progression of the interactive storytelling, obstacles emerge as difficulty makers to the progress and action of the player. They are elements that create interest in the player, motivating him progress, to reach its conclusion.

They can function also as guidance signals in space. There may physical or dramatic obstacles that hinder the progression, requiring to the player action in order to be able to progress.

A game does not give to the player a complete freedom of choices, but gives him the possible number of these—that is, imposes constraints, limiting their choice between the options offered—managing to give him a sense of freedom, whilst is conditioning him.

Setting a goal is of course the common method used [12]. The imposition of partial and final goals on the player immediately affects his behavior throughout the game, because everything he does will be in terms of achieving these.

The visual elements, in terms of visual composition, lighting and color, among others already seen, also manipulate the player's behavior.

The player moves naturally toward what draws your attention. In the film these aspects can only move the gaze of the viewer, but in an interactive medium like videogames to direct the gaze leads to targeting its path of action as well. Controlling where the player looks, is controlling also indirectly to where he will move [12].

### *3.3 Navigability*

A glance over the interaction of the player is of the greatest interest: the one that the aspect of navigability. Zangalo defines it as "the way the user moves in the environment, cognitively, what the player has to know and do, to move once in there and behavioral level, how to configure movement, how they express" [4].

Understand and analyze the navigability depends on a look at various aspects, such as how the player access and it is displayed the representation of the fictional world. The way the player access to that world, moves in it and performs actions, as well as all aspects that manipulate his journey and action, as the called indirect control, composition, color, lighting, and also aspects relating to land morphology, boundaries and obstacles.

A match is also a progression of sequences. There can be parts where there is divergence or parallelism. Soon after, it will have always to be a point of convergence and reunion in the argument. There are progressions as:

– No free will progression, to the image of cinema, with cinematographic sequences. They are totally immutable plots, pre-defined a priori, like the plots of filmic narratives.
– There are two forms of progression to plot the free will can coexist:

  (a) Sequence of events sortable and therefore partially built by the player himself, without challenging the game conclusion.
  (b) Parallel and alternative plots that will meet ahead at a point of the plot.

## 3.4 Kinds of Interaction

In a video game, the player is simultaneously an intervenient and a viewer: he both receives and sees information flowing from the storytelling, from an outside position, as also he contributes to these. In fact, he "*not only enters in the worlds games, as well he changes them and their elements*" [13].

Any game implies interactivity, since playing means to interact with objects in a game, make choices that are intended to support actions to obtain results in significant ways [14].

Salen and Zimmerman [14] analyze the relationship between interaction and "choice", developing what they call "molecule" of choice, arguing that the meanings in a game arise from the interaction of the player, from his choice and emerging the principle that should lead to a significant result. All interactive structure is built around this process. The interactivity that arises in this way takes place in various dimensions, from the explicit interaction with a concrete object in the game world, to the emotional and experiential interactivity with its fictional world.

The interaction model is another type of interface. This relates to how the player interacts with the video game universe, through an avatar or multiples, among other way [11].

– The camera model is another very significant interface, because it characterizes the genre of the game and the way the player looks to the world in the game, thus influencing also the way the player interacts with it and feels immersed in it.

– The several visual elements used, from the appearance of the main game view, feedback elements such as indicators, maps and colors, the display of the character, buttons, menus, and sometimes texts, are other interfaces that communicate information to the player within the game [11].

## 4 Fictional World, Telling and Player: Conclusion

A Videogame is an experiential living by the participant viewer: the player is placed in a world and plot that emulates that freedom. Production Design create visual and spatial situations fit for the living participation and interaction according the game script and its unfold

The Production Design appears as a visual interpretation of the script, plot and action, transmitting information about the narrative in terms of the script and its view [5]. Each game and its stages have different intentions and solutions. Each case is unique, with its own identity.

Between this two forms of experiential living in a world and two forms of narrative that can takes place in the fictional game's plot—the cinematographic linear narrative and the freedom of multiple paths from the player own action—the Production Designer that has to create all the visual and spatial situations so the observer/player so the player can observe, live, participate, feel, act and to be acted by the fiction Game's tale, as intended by the script.

They two ways complete each other, or struggle in opposite ways?

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# Part VIII
# Assistive Technology in Design

# Proaid E. Low Cost Neurological Wheelchair Design

**Gustavo Sevilla Cadavid, Andres Valencia-Escobar and Juliana Velásquez Gómez**

**Abstract** Low-income disabled people in Colombia routinely face problems in accessing reasonably priced assistive devices and disability products. The standard, low-cost Proaid M wheelchair, made with assembled laminated wood components and commercially available materials, is an object-based response to this problem. Based on the Proaid M design, a new model—the Proaid E—was developed for a 12-year old child with mixed cerebral palsy. The project combined the analytical systemic model "Disabled People-Built Environment" with a focus on user-centered design. The end result of this project brought about a marked improvement in the quality of life of an individual who had previously been denied the minimum necessary conditions for basic mobility.

**Keywords** Disability · Industrial design · Assistive devices · Ergonomics

## 1 Introduction

The design of assistive devices [1] is a response to those needs that emanate from an individual's limitations when interacting with the environment. This is achieved through the development of products that act as mediators between an individual's physical and cognitive characteristics and the functional characteristics of the environment. These products can dramatically improve the quality of life of disabled people, as well as older adults, people who suffer from obesity, those of small stature, and many others.

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Assistive devices should achieve their objective of preventing, redressing, controlling, mitigating and neutralizing an individual's deficiencies, activity limitations and participation restrictions. Their design must therefore take into account the anatomical, biomechanical, anthropocentric, cognitive and social characteristics of those individuals that become direct users of such devices. Universal Design, Inclusive Design, ergonomics and usability are some of the approaches that help to create products with high levels of functional adaptation based on physical, cognitive and socio-economic characteristics.

That last characteristic is important if one considers that many disabled people living in developing countries have to deal with challenging social and economic conditions, a situation compounded by limited access to assistive devices [2]. Under the current health system in Colombia, disabled people have access to a limited number of assistive devices and disability products. However, not all product groups established by the ISO 9999 standard are available or supplied through Colombia's Compulsory Health Plan [3]. This means that assistive devices, which are relatively expensive in Colombia, are unobtainable for a large majority of end-users, many of whom live in poverty [4].

It is at this point that concepts such as universal design, ergonomics and usability begin to play a key role in the development of assistive devices that meet a practical function, and that are adaptable to social and economic conditions, making them easier to acquire. Taking into account the difficulty that low-income disabled people have in accessing assistive devices, organizations such as the American Wheelchair Mission, the Free Wheelchair Mission and the Wheelchair Foundation, and individuals such as Doctor David Werner, have promoted local initiatives to produce assistive devices in developing countries, all of which have focused on the development of low-cost products.

This can refer to low-cost objects; objects that can be manufactured using low-cost tools; or objects that are cheaper than commercially available products and which carry the possibility of being made in a home environment. The Design Study Research Group (GED) at the Universidad Pontificia Bolivarianás Industrial Design Faculty in Medellín (Colombia) has been working since 2008 on the design of low-cost products that meet not only the physical needs of disabled people, but also take into account their financial situation.

The first product to be developed was the Proaid A—a wheelchair manufactured from PVC tubing (Fig. 1) that sought to meet the requirements mentioned above. The project also explored opportunities for the product to be homemade and/or manufactured on a local scale [5]. After addressing a number of issues in the Proaid A, work was then carried out on the design of a second wheelchair—the Proaid M (Fig. 2). This new model comprises five basic plywood pieces that are assembled to form a base structure. The wood pieces are joined together using a special slot system, rather than adhesives or mechanical fasteners. Front and rear wheels and brakes are then attached to this base structure. Commercial wheels may be used, or alternatively they can be built from two plywood sheets with circular

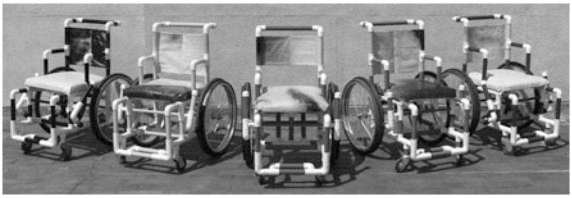


**Fig. 1** Proaid a wheelchair. GED archive

**Fig. 2** Proaid M wheelchair. 3D model. GED archive

perimeter. The sheets that are used to build the backrest, the seat and the footrest can be perforated to reduce the weight of the structure and improve air circulation.

The Proaid M wheelchair design—whose versatility can be seen through the use of low-tech tools and low-cost materials during the manufacturing stage—makes it possible for different adaptations to be developed to meet the specific needs of the user. To validate the level of adaptation to users with particular needs, a decision was taken to design a neurological wheelchair model for an individual suffering from cerebral palsy. The model was named the Proaid E. This project posed a challenge for the design team given the physiological, anatomical, cognitive, biomechanical, anthropometric and sociocultural complexities related to the user. The team also had to contend with the limited amount of available information concerning neurological wheelchairs, the medical nature of information, the high costs involved for this type of product and problems related to Colombian health system's supply model [6].

This project aims to highlight the importance of developing low-cost assistive devices for disabled people, and the benefits that these devices can generate. The project also underlines the value of interdisciplinary development teams, which in this case has comprised industrial designers, mechanical engineers, biomedical engineers and industrial design students at the Universidad Pontificia Bolivarianás Industrial Design Faculty. This led to the development of a neurological wheelchair that responds to functional, operational, technical-productive and aesthetic-communicative demands, and which is adaptable to local economic conditions.

# 2 Methodology

The Proaid E's design process followed a methodology adopted by the GED following their experience in research and product development. The process was based on user-centered design, the analytical systemic model "Disabled People-Built Environment" [7], and the methodology used during the Escuela de Ingenieria de Antioquia and the CES University's development of shaped seating. The different stages of the applied methodology were as follows:

- Information: In this stage, the user is observed in an active state in order to collect information about their psychophysical, sociocultural and technological requirements (requirements, characteristics, limitations, restrictions, criteria). The properties that are determined in this stage relate to the tensions between the user's characteristics, the object (the wheelchair) and the context i.e. problems that have to be resolved. An understanding of the user and the dynamics of the context provide information that can be introduced into the design process. A problem is then defined in terms of requirements and specifications.
- Formalization: In this stage, the form becomes tangible through models and prototypes, which are proposed for each of the tensions that make up the psychophysical, sociocultural and technological needs of the user and context, and which neutralize the problem in terms of functional, communicative and morphological dimensions. The objective of this phase is to convert the information acquired in the previous stage into a more formal proposal i.e. a solution to the problem.
- Conformation: This is the last stage of the design process, when the wheelchair that has been designed during the formalization process is introduced to the context, either as a product or service. A materialization process generates and adds a series of values to the proposed object, which provide it with meaning—be it commercial, institutional or cultural—and allows the user to recognize in this final form a solution to the original problem. It is the moment in which the wheelchair is introduced to the context and acquires a practical sense by the end-users.

# 3 Results

## *3.1 Information Stage*

As part of the information stage—and within the context of establishing the user's characteristics—an analysis of human factors was carried out that determined that the user of the neurological wheelchair was a 14-year old adolescent with athetoid cerebral palsy contracted during the prenatal stage as a consequence of twinning problems. The user was quadriplegic due to problems in the upper and lower limbs, and suffered from serious functional impairment (Fig. 3).

**Fig. 3** Project user. GED archive

The user's most characteristic feature is altered neuromotor function, demonstrated by an increase in muscle tone, the inability to maintain postural control and sudden changes in movement patterns. There are also issues related to visual perception and the proprioceptive mechanism, spatial awareness in relation to objects, altered body schema, altered language and communication skills caused by damage to cerebral areas and an increase in muscle tone in the nasal, oral, and pharyngeal area. Finally, the user suffers from epilepsy and intellectual developmental disorders as a result of neurologic injury.

The user cannot walk unaided and suffers from a complete lack of balance and handling ability. The user also suffers from joint disorders and problems in the torso caused by structural scoliosis. This is a person dependent on each and every one of their needs. It is difficult to source anthropocentric tables for the subsequent sizing of the wheelchair, as the user's weight and size is below average for their age and gender (masculine).

During the product characterization process, an analysis into the current state of the neurological wheelchair market was carried out. The results show that assistive device design has led to the development of many wheelchairs that have been adapted for users with neurological disorders. However, it was discovered that these chairs are five times more expensive than conventional wheelchairs. These products are equipped with a series of adaptations that allow the user to move around safely and comfortably. Most of these adaptations cover basic requirements and meet the comfort needs of patients, and in particular children.

A review of existing wheelchairs shows that the majority appear to have three subsystems: (1) Chest and abdomen support; (2) Upper and lower limb support; and (3) Head support. Most feature detachable and adjustable armrests at user height, and have two detachable footrests with a height adjustment option to match the user's anthropocentric dimensions. They also include padded and detachable head support, lower back support and a fastening system using straps.

A characterization of the context showed that in terms of urban accessibility, steps close to the entrance of the user's home were inadequate for wheelchair use, either because they lacked private paving or because they were poorly built and

**Fig. 4** Companion and user dealing with restricted movement. GED archive

were more than 3 cm high. There were no wheelchair access ramps in the surrounding four blocks of the user's home, while the nearby sidewalk surfaces were irregular and in poor condition, which impeded mobility.

In terms of architectural accessibility, the main problem for the user and the carers were stairs. The user's bedroom is located on the second floor, meaning access to the area is difficult, while assistance from two people is always required. The small spaces limit mobility for the user and the carer (Fig. 4). Doors are another major obstacle, especially for wheelchair users. This problem is difficult to resolve because of the minimum dimensions laid out by architectural rules, and the fact that the direction in which the doors open is not indicated. The bathrooms are unable to provide safe and optimal access for the user as the sink and toilet are too high and there is a lack of space to access them from a wheelchair.

During the activity analysis, only one action was selected on the basis that it was the most difficult to carry out. According to the carers, accessing the bathroom was identified as one of the most dangerous basic activities due to the risk of falls and injuries caused by the user's functional limitations, their weight and inadequate space and objects. The carers occasionally lost their balance while carrying the user due to the lack of support systems in the bathroom that the carer could grip. This created insecurity and increased the risk of falls. The shower was also a risk factor due to a poor water runoff system that also increased the risk of falls. This carer subsequently chose to wash the user in bed, which created further complications.

## *3.2 Formalization Stage*

The key concept was adaptation. This was explained in terms of "adaptive mobility", a basic concept of the previous Proaid models. Based on this premise, the project can be properly adapted to the needs and mobility issues of low-income disabled people. Another conceptual factor that was taken into account was the possibility for the wheelchair to be made in the home environment. This would represent a shift in current thinking that wheelchair users cannot be part of the manufacturing process. The process also sought to adhere to the directives of the World Health Organization

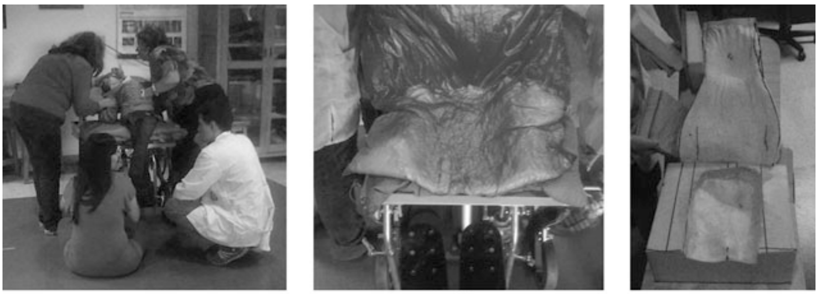
[8], which state that all projects of this kind should take into account the product's entire lifecycle, including an analysis of the user, their training from the moment they receive their wheel and production and maintenance of the wheelchair.

Once the conceptualization of the product had been established, a next stage examined the design of alternatives. This activity in the design process results in a set of solutions to the problem, with a degree of descriptive definition. An experimental search method based on Ritchey's Morphological analysis was used [9]. Computerized models using Solid Edge software were then created, while structural analysis of resistance, rigidity and stability was carried out according to the model put forward by the GED's experimental morphology research group [10]. At the same time, the minimum ergonomic conditions to guarantee comfort and safety were defined. This process allowed the form to evolve, from initial ideas to the final model.

### *3.3 Conformation Stage*

The final design requirements were determined from ergonomic factors (biomechanics, anatomical anthropometry, socio-economic) and object-based factors (form, function, materials, structures, color, etc.), and tested to see which possessed the most formal, functional and productive feasibility. Because the user suffers from asymmetrical posture and spinal deformation caused by scoliosis, the wheelchair's design should address the space created when the user's back comes into contact with the support area. To resolve this issue, the Biomechanics Laboratory at the Escuela de Ingenieria de Antioquia and CES University helped to develop shaped seating [11].

The shaped seating is a support surface made from polyurethane—26 density and 50 mm thickness—that matches the user's anatomical shape and allows a close fit between the user and the seat. This type of seating helps prevent the formation of pressure ulcers in adults and helps children to maintain good posture while offering comfort and support (Fig. 5a–c).



a b c

**Fig. 5** **a** Taking a mold of the user's spinal column, back and pelvis. **b** Fabrication of the counter-mold of the user's spinal column and pelvis. **c** Shaped seating

The best postural position for the user was achieved when the front part of the seat was tilted backwards at an angle of 5°, creating an angle of 145° between the user's back and the seat. A pelvic belt should be attached to avoid slipping and to help create optimal posture. In addition, support should be added on the right side of the user's abdomen, as the user tends to strain when uncomfortable, which increases spinal curvature related to scoliosis. To compensate the user's inability to maintain postural control of the neck and head, the wheelchair must be fitted with head restraints at the sides.

In order to create an efficient drive system, it was decided that the wheelchair's rear wheels should be bigger than the front jockey wheels. Standard bicycle wheels with a 16″ diameter and a 1.5″ thickness were fitted, with aluminum rims to reduce weight, tires for shock absorption and steel blocks for lateral support. The commercially available jockey wheels were 5″ in diameter and located at the front of the wheelchair, and finished with a polyurethane coating finish—ideal for indoor areas and hard and smooth ground surfaces. For the drive system, a standard MTB bicycle handlebar was chosen as it provided grip and enough mechanical advantage to allow interaction with the wheelchair. A special piece of equipment was designed that joined the wooden structure with the stem and handlebars. A standard break pad system was selected and attached to the structure by a mechanical fastening system. The central structure of the wheelchair keeps the same slot-based assembly system used for the Proaid M, which is made from laminar pieces of plywood and proved to be efficient and safe (Fig. 6). However, the edges of the pieces were adjusted to adapt the ergonomic variables to the wheelchair user.

For the formal and functional physical modeling, a number of prototypes using 18 mm-thick plywood sheets were assembled (Fig. 7a). Each prototype underwent systematic and sequential physical, mechanical and production testing (Fig. 7b), which yielded information for formalization that was then fed back into the process. All prototypes were made using technology that a user could be expected to utilize in a home environment. The structural tests for each of the prototypes were carried out according to the test protocols of the regulation ISO 7176-1 [12], and through Whirlwind International's proposed model, which conforms to the guidelines of the ISO standard, but is executed with the help of simple tools and materials [13] (see Fig. 8).

**Fig. 6** Slot-type connection

a b

**Fig. 7** **a** Pieces of plywood sheeting for a prototype. **b** Prototype ready for testing

**Fig. 8** Lateral static resistance test of the structure

**Fig. 9** Dimensional and anatomical fitting test of shaped seating. GED archive

Usability tests were carried out using the GED Ergonomics Research Group's product valuation proposal [14]. Anthropometric and anatomical fitting tests were carried out (Fig. 9), while comfort levels from a perceptive standpoint were evaluated with input from support workers (physiotherapists, bioengineers, physiatrists) and the user's carers. The carers helped to identify different aspects of the product


a b

**Fig. 10** **a** User with final prototype. **b** Individual pushing the Proaid E neurological wheelchair

that needed to be improved, which led to modifications being made to better suit the user's particular needs. This was done according to the guidelines of user-centered design and participatory design.

During the detailed design and final production process, a prototype was developed and given to the user's family (Fig. 10a, b). The project also identified how the wheelchair could be mass-produced using numerical controlled machinery. This would reduce production costs if the project were expanded.

## 4 Conclusions

The most significant conclusion to be drawn from this project is that through a concurrent and user-centered design process, it is possible to meet the specific needs of disabled people with object-based solutions. These can be adapted to meet not just technical and medical requirements, but also the group's aesthetic and economic needs. The design of support products like the Proaid E is therefore an exciting challenge, albeit one that is full of uncertainty and challenges from a technical, financial and business standpoint. However, the designer's voice must be heard for the benefit of disabled people.

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# Ubiquitous Notification Mechanism to Provide User Awareness

**Gustavo López and Luis A. Guerrero**

**Abstract** Awareness could be defined as the knowledge that the user has of a particular activity, either individual or collaborative. Good awareness mechanisms provide information to the user at the right time so that s/he can know what is required for her/him to do before s/he is required to do it. Notification mechanisms are a key factor to provide awareness. Ubiquitous technologies can change the paradigm in which notifications are delivered to users. This paper describes the concept and characteristics of awareness, and how researchers have applied different notification mechanisms to provide it. With the lessons learned from 4 project implementations, we propose a service-based plug-and-play framework that models different notification mechanisms that could be used to provide user awareness.

**Keywords** Human factors · Warning design · User awareness · User experience design · Ubiquitous computing

## 1 Introduction

Notification mechanisms have been discussed by the software development community for several years. Typically, they are used to provide awareness. *Awareness* is defined as the amount of knowledge that a person has about a topic in particular. In the Computer Science community, the term awareness has been applied in several contexts, and one of the most common is the Computer Supported Cooperative Work (CSCW) in which, even though, there is still a discussion on the topic, most authors agree that awareness requires the user to know what to do, in time to do it [1, 2].

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Recent advances in technologies such as Ubiquitous Computing are changing the way notifications are delivered to users. *Ubiquitous Computing* was defined by Mark Weiser as the reality in which computing appears to be everywhere. The basis of Ubiquitous Computing are small, inexpensive, and robust networked processing devices, distributed and embedded in the user's environment [3]. We believe that by using ubiquitous devices as means of notification, user awareness could be increased and improved.

One of the trends in Ubiquitous Computing are *Augmented Objects*, which are common objects, augmented with computational and technological capabilities [4]. These objects have traditionally been used to record or gather information from the environment that can be used for diverse purposes. However, they can also be used as means of notification, if actuating capabilities are added.

This paper proposes a service-based plug and play framework in which augmented objects can be used as means of notification in several contexts. Our framework was developed with the experience gathered from several project implementations and a literature review delving into the topic. The literature review was mainly focused in notification mechanism applied in CSCW scenarios.

## 2 Awareness

The term awareness differs according with the area of studies addressing it. For instance, in Ubiquitous Computing the term awareness is usually associated with context-aware pervasive systems [5]. For the CSCW community, awareness is a property of the user. They define awareness as the knowledge that a person has about the activities that other people collaborating with him/her are performing [6].

For our purposes awareness is defined as the knowledge that the user has of a particular activity. This knowledge could come from another user performing activities, tasks scheduled to be executed, or any other piece of information that allows a better performance in the user activities. Awareness implies getting information and somehow providing it to the users. To maintain user awareness, notifications are required. The main goal of a notification is to deliver current important information in an efficient and effective manner, without interrupting or distracting the user except when a disruption is unavoidable [7].

Bødker and Christiansen explained that in order to keep the user aware a balance is required in the delivery of notifications. If notifications are continuous, users might take them for granted and work around them or stop paying attention. If notifications are not delivered in long periods of time, users migth forget what they are supposed to be doing [8].

One example of continuous notifications is the use of sound notifications for messages, incoming emails, social media announcements in mobile phones. For common users the amount of notifications is so high and continuous that they stop paying attention. Increasing awareness usually causes privacy and security issues. This situation forced the community to search a balance between privacy and awareness [9].

## *2.1 Technologies Used to Provide Awareness*

The discussion of how to apply technologies to support awareness has been around since the late eighties [10]. Most of the work performed between 1985 and 2005 was focused on how to provide awareness by using traditional Graphical User Interfaces (GUIs). One of the first attempts to use other type of interfaces to provide awareness was *Media Spaces* [11]. During the 90s, specialized software that gathered information from other applications provided graphical feedback to the users increasing awareness [12, 13].

We conducted a literature review to determine which notifications mechanisms have been used in the past years to provide awareness. Our review was conducted systematically to answer the following question: *In what extent have ubiquitous mechanisms been used to provide awareness*?

Our search was performed in three of the main scientific repositories available: IEEE Digital Library, ACM Digital Library and Springer Link. We included papers that proposed notification mechanisms and review them to determine if the notifications mechanisms were considered traditional (i.e., graphical user interfaces) or if they could be consider augmented objects or ubiquitous computing devices. The literature review focused on applications in the CSCW domain. Initially, 400 papers were reviewed (title and abstract), 126 were considered for further analysis (full text revision) and 63 papers were finally included (i.e., they proposed a notification mechanism).

Figure 1 show the results of our literature review. 46 % of the reviewed papers still use traditional interfaces as means of notification. Moreover, 13 % use public displays that are commonly shared traditional interfaces. A large use of mobile devices can be distinguished from the results of our review: 35 % of the proposals use mobile devices (especially phones) to deliver notifications.

The remaining 6 % of the reviewed papers use what could be called ubiquitous devices (e.g., light display, smart devices and wearable technology). The light is used to control and synchronize time during meetings (i.e., the intensity and color

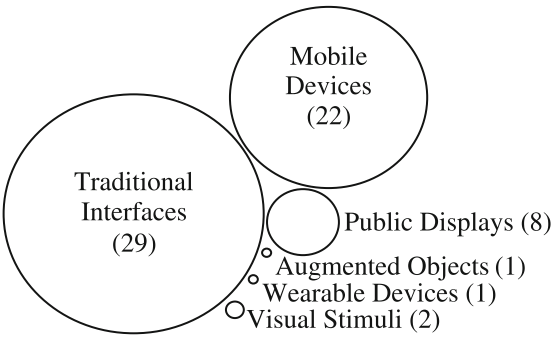


**Fig. 1** Proposals of notification mechanisms found in the literature review. Six types of mechanisms were found. *Circle size* shows the amount of papers for each notification mechanism

of a light notifies the users that their talking time during a meeting is ending). The augmented object reported in one of the papers was placed in a house, in which they notify the users of several tasks waiting to be performed. Finally, the wearable device reported was a belt, which had vibration capabilities to notify different situations.

## 3 Prototypes of Notifications Mechanisms for User Awareness

We have developed four different notification systems applied to provide awareness: one applied to urgent notifications for emergencies, other for emails, other for visitors in offices, and the last one for collaborative document editing. The rest of this section is dedicated to describe the context in which each solution was deployed, the system's characteristics, and architecture.

The first two systems were developed without third party applications (i.e., the whole system was implemented as a solution for a problem. The other two systems required access to third party applications (i.e., not managed by the developers) accessible through some kind of API.

### *3.1 Notifications for Emergencies*

In this development, notifications were used in an emergency context. Our particular application was focused on Sudden Infant Death Syndrome (SIDS). Our system considered two main risk factors of SIDS [14]: Prone or side sleeping, and high or low ambient temperature.

To address the problem caused by SIDS, we developed a ubiquitous system that monitors babies, and notifies parents if potential problems are detected [15]. The monitoring was performed using wearable technologies attached to the child clothes and the notification mechanism was through mobile devices (i.e., parent's phone).

The notification was delivered in the most intrusive way possible, due to the possible consequences of not attending the message. The phone started to ring and vibrate (similar to a phone call) even if the phone was set to silent mode. The only way to stop the warning is by pressing a button in the application.

Figure 2 shows the architectural diagram of the solution, we unified the architecture diagram of this system with the one for visitors in office (next section) because they followed the same pattern. This system was evaluated with 5 users in their actual context. Additionally, a Wizard of Oz evaluation was performed to test the applicability of the system.

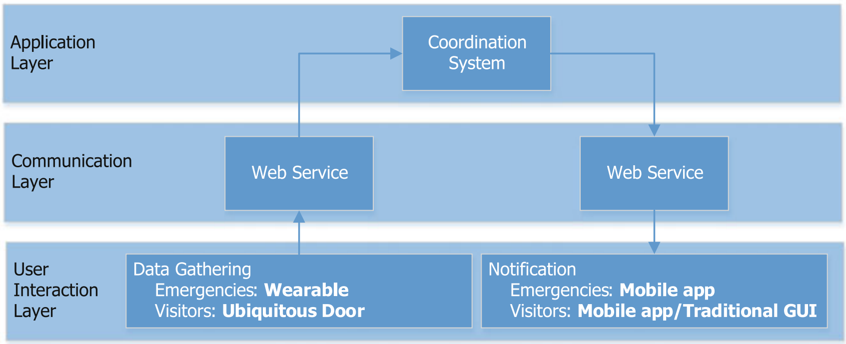


**Fig. 2** Architecture pattern 1 (Without third party applications). Applied in "notifications for emergencies" and "notifications for visitors in offices". This architecture only requires the coordination system in the application layer

## *3.2 Notifications for Visitors in Offices*

Answering machines have been around for more than 30 years. We used a ubiquitous mechanism to allow communication between users even when one of them is not present. For this purpose, the system allows users to leave a video/audio message when they arrive to an empty office (i.e., owner is not present). Figure 2 shows the architecture of this system.

To solve the problem of communication, we developed a door with a recording machine embedded. Our door messaging machine allows people to record a message that would be sent to the office owner via email. Furthermore, we combined this system with the notifications of particular emails (see Sect. 3.3) to provide more awareness mechanisms of the same situation. This system was validated through storyboards.

## *3.3 Notifications for Particular Emails*

Email is an essential tool for most people in both personal errands and work. In web based applications, the amount of messages, including spam, is large. In this case, we used notifications to avoid that users lose time checking non important emails [16]. Our solution provided a notification mechanism that allows users to know if they have important emails in their inbox without having to see the list of received emails. Figure 3 shows the architecture diagram of this system.

The notification was delivered with a ubiquitous device, using a post-it note metaphor. Every time an important message arrives a post-it note is placed somewhere in the user's context. The system was validated with 5 users, using the

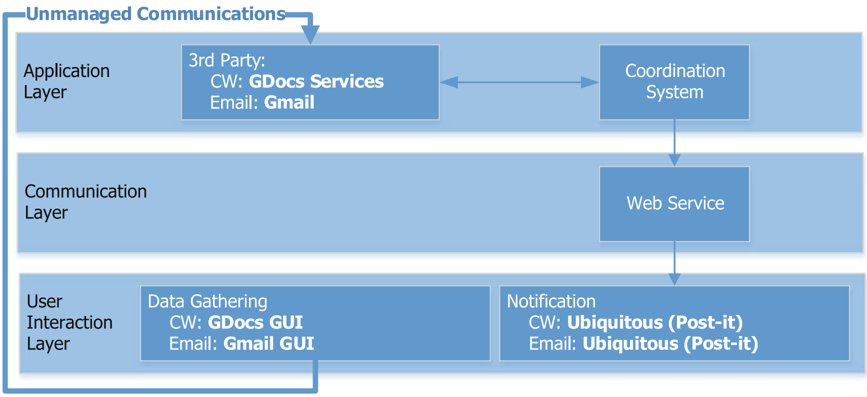


**Fig. 3** Architecture pattern 2 (with third party applications). Applied in "notifications for particular emails" and "Notifications for collaborative document editing"

diary study in the user's work and post-it notes were configured to be placed in front of the computer monitor. The notification mechanism was a post-it note that said: *You have mail in Gmail*!

### *3.4 Notifications for Collaborative Document Editing*

In this case, we developed a notification mechanism designed for collaborative document editing [17]. There are several computational tools to support collaborative document editing. In our prototype, we used Google Drive, an online office suite for text, spreadsheets and slides. The service currently allows real-time collaboration (i.e., changes are reflected immediately). The service offered by Google, already provides notifications, however they are only available via their GUI.

We developed a notification system based on the post-it note metaphor already used for notification of important emails. This system connects with the services provided by Google to determine if any change has been done to the documents when the user is working on and displays the notification accordingly. The system was developed to support the writing strategies proposed by Lowry et al. [18], and evaluated in the scenarios, proposed by the authors. The architecture of the system is shown in Fig. 3.

### *3.5 General Considerations and Lessons Learned*

This section summarizes the lessons learned from the development of the four prototypes described in this paper and the results of our literature review. We used


**Fig. 4** Notification mechanism used in the four prototypes. *Left* “notifications for emergencies”—mobile application. *Center* “notifications for visitors in offices”—augmented door and mobile device. *Right* “notifications for particular emails and collaborative document editing”—post-it note placed in the work environment

two main notification mechanisms: a ubiquitous device (post-it note) and mobile applications (see Fig. 4).

It is clear that notification mechanisms are useful in several contexts. The main drawback of such notifications is the intrusiveness that they provoke in the user’s daily routine. The level of intrusiveness needs to be controlled. For instance, the notification for emergencies used a mobile application and had a very high level of intrusiveness it was almost impossible to ignore it. Nevertheless, the notification for visitors in offices (that also used a mobile application as notification mechanism) had a lower level of intrusiveness, the same as just getting an email (i.e., it could be considered or neglected and subsequently revised).

The “notification for emergencies” prototype provided evidence that very disruptive notifications are sometimes required. In this case, users were willing to use the system due to the perceived value. A cost/value evaluation is necessary to determine the level of disruptiveness accepted by the user in each context.

In the case of the “notifications for particular emails”, we realized that sometimes notifications need to be removed without them being noticed (i.e., if the user performs the task without noticing the notification, it should disappear). Our experience using ubiquitous notification mechanisms was satisfactory and drove us to think about their applicability in more complex scenarios.

While building the “notification for office visitors”, we noticed that the architecture was very similar to the notification for particular emails. This allowed us to demonstrate that notification and monitoring mechanism could be changed and the system kept working fine. We have to mention that the developed notification mechanism is called ubiquitous as a reference because it is not everywhere, but it helps to build the ubiquitous computing context. The notification is placed only in the user’s work context.

Our last development was focused in supporting the collaborative editing of documents. This prototype allowed us to determine that it is not enough with the information gathered from the user (implicit or explicit), but is also necessary to understand the coordination strategies in order to apply technologies to improve awareness.

Moreover, the "notifications for collaborative document editing" demonstrated that the same notification mechanism (post-it) can be applied in several contexts (particular emails and collaborative document editing).

All the prototypes described in this paper use web services in the communication layer, this allows replication and redundancy of notification mechanisms.

## 4 Framework Proposal

After we developed the systems mentioned in Sect. 3 and with the lessons learned in mind, we propose a framework that models several systems and allows the use of ubiquitous notification mechanisms to provide user awareness. As it was mentioned by Schmidt [1] awareness is not a product, therefore it cannot be explicitly modeled in a framework. However, the ability to use different notification mechanisms and a coordination system assures some level of awareness.

Our framework is composed by three layers: the user interaction layer, the communication layer and the application layer (see Fig. 5). First, the user interaction layer incorporates both mechanisms to gather data from the user and to deliver information to him. In general, this layer embodies all the parts of the system that interact with the user either explicitly or implicitly. An additional component allows the configuration of the "coordination system".

The communication layer is necessary to assure connectivity among the parts of the framework. Although several other integration mechanisms could have been applied, our framework is based on Web Services because we assume that all the ubiquitous devices provide their functionality via web services as they were developed following the same methodology [19]. The discovery service is essential to allow the incorporation of new notification mechanisms.

Finally, in the application layer there are two kind of systems, the coordination system that allows data gathered and other information to be used in order to notify the user and assure awareness, and third party applications that are used to gather more information about the user's activities. Notice that communication between the user and third party applications is modeled in our framework, however, such communications cannot be neither managed nor monitored.

A transversal axis verifies privacy and security, specially focused on the communication layer. Notice that neither third party applications, nor communications between the user or coordination system and third party applications are considered.

In this paper, we do not further discuss about the privacy and security transversal axis, as the authors are not experts in the topic. However, collaboration with experts

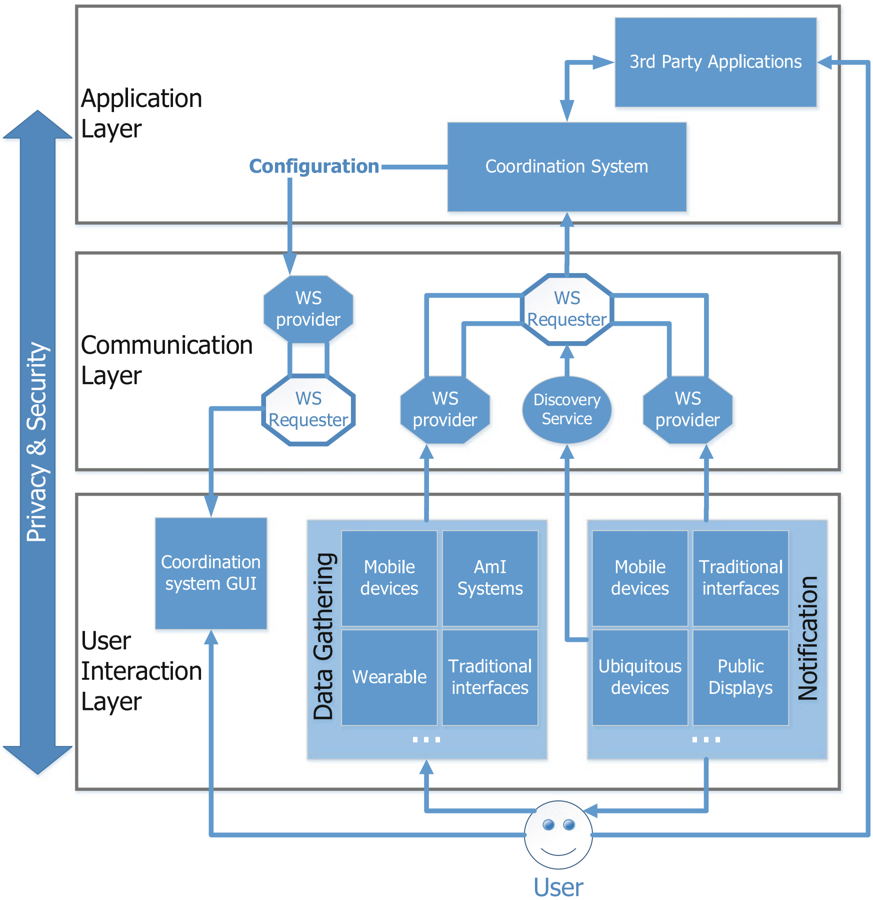


**Fig. 5** Ubiquitous notification framework: overall architecture

will be considered to describe the required policies to assure the user's information safety.

One of the main components of our framework is the coordination system. This system is the heart of the operation, and allows collaboration among several users or between several notification mechanisms in the same context. In order to work, the coordination systems use all the information gathered from the user via the interaction layer or information that is stored in third party applications. With that information and the available notifications mechanisms registered via the discovery service, the user is notified of upcoming activities that require his/her attention. The coordination system settings need to be set by the user, thus a GUI is provided to allow such configuration.

As an example, imagine a setting in which your work office door is embedded with capabilities that allow change of colors (i.e., red means you have an upcoming meeting, green free for the next hours). If you as the user add an event to your calendar (3rd party application) the coordination system will access that information, the door will be available as a notification mechanism and it will be used to notify you of your upcoming meeting. When you arrive at your office your door will be red. However, if the information gathered from you (data gathering mechanisms) places you somewhere else, the door will not be used as the notification because you would not see it in time, therefore it will fail as a mechanism to provide awareness. In this case, the coordination system will use other means of notification.

Our framework is service-based and works in a similar way to plug and play device in the user interaction layer. Moreover, since the main processing is performed by the coordination system and it could be in the cloud, several devices or systems for either monitoring or notifying could be used simultaneously.

## 5 Conclusion

In this paper we presented a service-based plug and play framework that support the use of different means for notification and data gathering mechanisms to provide user awareness. Our framework was developed from the experience gathered developing four systems and a literature review in the topic.

Results from the literature review show that less than 10 % of the included research papers proposed system that used augmented objects or ubiquitous devices as means of notification (i.e., traditional user interfaces are still widely used to provide awareness). Several experts in the topic envision ubiquitous computing as one of the most plausible trends in computer science, therefore, we decided to delve in the topic and address the use of ubiquitous devices as means of notification to provide user awareness.

Our framework is composed of three main layers: user interaction, communication and application. The user interaction layer comprises all the components that have interaction with the user either explicitly or implicitly. The communication layer uses the standard for web services. It must be noted that there are some communications that are neither managed nor monitored.

Finally, the application layer comprises the coordination system that decides which notification mechanisms to use given the gathered information, and third party applications with which the user interact directly and information is retrieved from them.

The framework proposal models all the non-traditional mechanism identified during the literature review and the four prototypes mentioned in this paper. This evidences that our framework is a good fit to design new systems that use ubiquitous devices as means of notification. One of the main advantages of our framework is that it allows the use of different notification mechanisms for the same purpose. Moreover, it allows the simultaneous use of notification mechanisms to increase the level intrusiveness when it is necessary.

Security and privacy policies must be addressed, however, the contribution of experts in those areas is required to determine the correct description and application of privacy and security policies. Our work has two main limitations. First, all the systems were developed by the same team, therefore patterns in the construction process tended to appear quick. To further validate the framework, other development teams need to apply it and assess its applicability. Second, the literature review that we carried was focused on collaborative systems leaving aside notification mechanism applied in other contexts. Other systematic review is required to incorporate research papers that were not included in our literature review.

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# Assistive Technology for People with Low Vision: Equipment for Accessibility of Visual Information

**Sabrina Talita de Oliveira, Julia Vieira Bozo and Maria Lucia Leite Ribeiro Okimoto**

**Abstract** Assistive technologies help people with visual impairment to improving the quality of life in the understanding of information and mobility. Regarding people with low vision are some devices that enable information accessible, expanding the graphical content, visual and text. This paper presents the main equipment for accessibility of information for people with low vision. It consists of bibliographic review and in brands that offer products to these people. The results demonstrate assistive technology offered in the market and promotes a comparative analysis of fixed amplifiers and portables, smart glasses and loupes, in order to trace the main features of these devices while aid products for people with residual vision.

**Keywords** Assistive technology · Visual information · Accessibility · Low vision

## 1 Introduction

Assistive Technology (AT) is still a new term used to identify all the resources and services that contribute to provide or expand functional abilities of people with disabilities and consequently promote independent living and inclusion [1].

It can also be understood as "equipment, services, strategies and practices designed and implemented to alleviate the problems encountered by people with disabilities" [3]. AT is a tool or resource used in order to provide greater independence and autonomy for the disabled person. Some of its objectives are to provide quality of life and social inclusion for people with limitations [5].

Thus, AT can help to minimize the visual impairment of people with low vision. Low vision means severely impaired vision after optical correction, but with some

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potential to use the available vision, with or without compensatory visual strategies such as optical aids and environmental modifications, to plan and perform daily tasks [4].

For the World Health Organization (WHO) in the International Classification of Diseases, ICD-10 [10]: Low vision is defined as visual acuity in the best eye with the best optical correction, less than 0.3 and better or equal to 0.05. In the presence of visual field impairment, WHO recommends that for low vision the visual field is less or equal to 20° and greater than 5° at its largest diameter around the point of attachment.

In this scenario, among the 25 million of Brazilians who have some type of disability, 16 million and four hundred thousand individuals are diagnosed as disabled low vision [7]. However, these disabled people often adapt to voice programs, commonly used by the blind, or the magnifiers screens, little effective when the interface has no color contrast. It is important to emphasize that these people hardly identify small variations of nuances between colors. These situations lead often to the decreased ability of these users to see with little vision they have [11].

Given this perspective, it is necessary to create conditions so that the visually impaired can be decreased and the communication process occurs. The transmission of information for low vision should be possible through the use of ATs, in order to ensure significant improvement in optical conditions to improve the understanding of the visual content of the surroundings.

In this context, and noting that the literature in the area show little chance of aid equipment for people with low vision, this paper has the objective: to demonstrate existing equipment to the accessibility of text, image, graphics and illustrations for the person with low vision.

Thus, the specific objectives of this study are:

- Clarify on the concepts of AT and low vision;
- Relate the importance of AT equipment design that enhance the visual sense of the person with low vision;
- Reflect about the AT Design for such public.

The methodology of this research is divided into: unsystematic review of the literature and case studies about TA products that qualify visual information content: books, magazines, instructional courseware, plates and bus routes for people with visual disabilities, specifically for low vision.

In the results section we present equipment that make accessible information to low vision. Among the equipment presented are: voice synthesizers; text readers fixed and portable, magnifying loupes.

At the end of this study we present a comparison table of assistive technology for low vision and we discus about the possibilities for improvement of existing aid equipment, as well as the designer's contribution on the accessible design of products that enhance the usability of people with low vision.

## 2 Low Vision

A person with low vision (LV) also called Sub-Normal View (SNV) has a severe vision loss that cannot be corrected by medical or surgical treatment or conventional glasses. It is related to the visual capacity of the person. The visual capacity of low vision is between 20/40 and 20/200, after optical correction. A person with 20/200 vision is an individual who can see an object 20 ft away while another person with normal vision can see 200 ft away the same object. It can also be described as any degree of weakening which can cause visual impairment and decrease visual performance [11].

The Brazilian Decree 5296, 2004—Chap. IX “Final Provisions”, Article 70 provides the legal differences between blindness and low vision [8]:

- Visual Disability—Blindness mean visual acuity equal to or less than 0.05 in the better eye with best correction optics;
- Low vision mean visual acuity between 0.3 and 0.05 in the better eye with the best optical correction; the cases in which the sum of the measurement visual field in both eyes is equal to or less than 60°; or the simultaneous occurrence of any of the above conditions.

A person with low vision, depending on the condition, has commitments related to decreased acuity and/or visual field, difficulty in adaptation to light and dark and color perception. However this individual uses or is potentially able to use residual vision in the planning or execution of certain tasks [2].

Low Vision (LV) means impaired visual function, but cannot be understood as blindness. The author also proposes that the terms LV and SNV are usually used to define the situation in which the eye has some of its visual impulse channels changed irreversibly. Still, we can define as low vision person the individual that the vision loss is an obstacle to the normal development of the individual’s life and needs special correction [6].

This deficiency is related to problems such as:

- Dimming of vision;
- Blurred vision;
- Fog or film on the eye;
- Only view extremely close objects or loss of distance vision;
- Blurred vision;
- Spots in front of vision;
- Color distortion or color blindness;
- Visual field defects;
- Tunnel vision;
- Lack of peripheral vision;
- Abnormal sensitivity to light or glare;
- Night blindness.

Thus, the LV is in an intermediate position between the reality of people that see normally and the total visually impaired. The person with this disability have limitations relating to perform certain functions and is not treated as blind, because has residual vision that allows to perform some tasks perfectly. Thus, this paper aims to present AT to enhance and stimulate residual vision.

## 3 Case Studies

In this section we present some aid product to people with low vision—AT. These devices are designed to: enlarge texts; graphics enhance; differentiate colors; enable the illustration or closer picture of the visual field of the user to recognize volumes; differentiating textures and decode text characters. The equipment are presented individually and later in a comparative table of the features of each.

### *3.1 Electronic Magnifier*

The American company Hims Assistive Technology has developed a portable electronic magnifier for low vision users, known as Candy 5 HD II. The magnifying glass has imaging capabilities for high definition, cable that meets right-handed and left-handed users. The company received the award Red Dot Design in 2015 for this product. The Electronic Magnifier allows the focus control, and zoom in with three cable positions. The screen has size of 5″ LCD. The product can be configured in mirror mode, which allows the user to direct the front of the product to the mirror, the image of this will be captured and displayed on the screen in high definition, allowing the user to see their own image, focus some point and expand any region. The product has rechargeable battery (Fig. 1).

The Candy 5 HD II has the following characteristics:

- High definition on the LCD screen of 5″;
- Continued Expansion of 2.5× to 22×;


**Fig. 1** Candy 5 HD II in operation. *Source* Tecnovisão [9]

**Fig. 2** Candy 5 HD II. *Source* Tecnovisão [9]

- Video enlarger;
- Central position capability with high definition camera and autofocus;
- Can be used as a magnifying glass or the fixed support;
- Mobility for different environments (Fig. 2).

The images are presented with high resolution and defined colors, allowing reading maps, charts, catalogs and material with vibrant colors. Enables color mode B/W (black with white background), reverse in high-contrast W/B (white on black background) and change the text color definition with the background in order to enhance the readability of information.

The magnifying glass has the cable 3 positions, the buttons are at your fingertips when the person holds the cable. The video magnifier loupe capture images when the person presses the right button. It has a cable that can be foldable for use directly over or in front of the visual information support.

With the zoom feature distance it is possible to approximate visual content surrounding the subject, such as plates or bus routes. When set in mirror mode, allows the user to see their own image in the mirror (self-portrait), which can assist in the performance of daily activities, brushing your teeth or makeup.

## *3.2 Enlarger Portable: E-Bot*

E-bot is a portable video magnifier, which has OCR technology (Optical Character Recognition), a technology that recognizes characters from an image file. This file can be scanned, handwritten, typed or printed. Thus, through the OCR technology is possible to obtain an editable text file by a computer.

This equipment allows content that is far away and enables connectivity to wireless Internet network. Thus, when connecting the amplifier to a mobile device through the Internet network, or USB computers, the user can see and interact with the content of text or image at a distance, from the possibility of expansion and reduction. To change the zoom level, image mode and contrast level, the user must use a remote control that comes with the product, the E-bot ADV (Fig. 3).


**Fig. 3** E-Bot allows access to instructional content textbooks or magazines. *Source* Tecnovisão [9]

The enlarger creates a wireless Internet network to connect with a tablet without requiring network access. Thus, the visually impaired need to install an application on the mobile device to establish an automatic connection to the equipment.

It allows the image scanning and through OCR technology enables image text reproduction through the voice synthesizer. Enables activation and pause OCR technology directly from the mobile screen or by using the remote control. The equipment allows compact structure, weighs 2 kg and promotes mobility.

The product has the following characteristics:

- Compatibility with mobile devices;
- Connection via wireless internet network on mobile devices;
- Channel wireless network itself;
- Connectivity with computers via USB;
- Zoom in and Zoom out;
- OCR with voice synthesizer;
- Battery for use of up to 4 h.

### *3.3 Video Magnifier Portable: E-Bot Pro*

This enlarger video is a portable player compatible with mobile devices. It has magnifying loupe with control adapted to the feature game controllers (joystick) and OCR technology for translating texts (Fig. 4).

When the E-bot PRO device is connected to a wireless internet network with a mobile device, it is possible for the user to read and adjust from gestures on the screen (touch screen), enlargement or image reduction, text and background colors.

The product can create wireless channel from installing an app on the mobile device. The user can also connect the device to computer through USB, and also with the TV or monitor through HDMI cable.

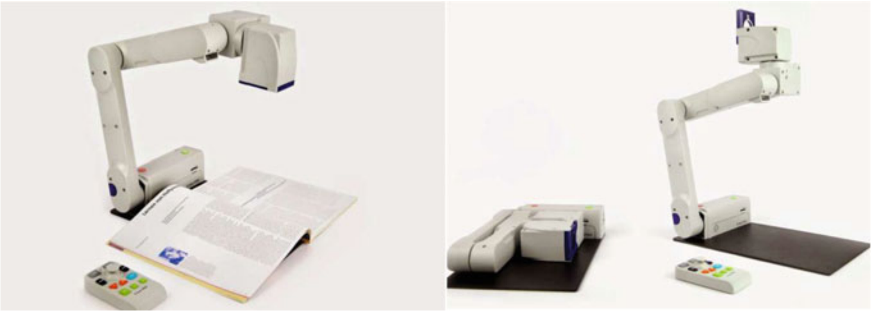

**Fig. 4** E-Bot Pro. *Source* Tecnovisão [9]

The user can also move the camera to read a document, or use the joystick control or touch screen. The product is powered and the camera memorizes the position to read when a person switches the display mode. This allows, for example, a student concentrate on the teacher. The remote control provides an intuitive coordination and teachers can also use the control to help students find the text on the board or paper.

This video magnifier capture the entire page of text and plays through voice synthesizer. It also allows to be saved capture file in .JPG or .TXT format. The product has storage possibility in memory card for later transfer on computers.

The product weighs about 3 kg (weight measurement in Brazil) and when folded, a more compact structure can be carried in a backpack. It has rechargeable batteries and works up to 4 h continuous use.

The product has the following characteristics:

- Compatibility Ipad and Android;
- Channel itself for a wireless network connection with mobile devices;
- Connectivity with computers, TV or monitor;
- OCR translation system with voice synthesizer;
- Joystick Control and touch screen camera movement;
- Storage via memory card, the .JPG or .TXT file formats.

## 4 Discussions

In this session we present a comparative table of analysis parameters that we perform in the equipment presented. Here we draw a comparison of the main features of these devices as aid products people with low vision. Compared using the following parameters: capacity expansion; color models in which information can be converted into the apparatus; dimensions; mobility; integration possibility with other technologies and control in the own product structure (Table 1).

**Table 1** Comparative analysis of assistive technologies

| AT | Functions | Color adjust | Dimension | Mobility | Integration technologies | Control |
|---|---|---|---|---|---|---|
| Candy 5 HD II Electronics and video magnifier loupe | High definition zoom 2.5× to 22×<br>Autofocus | Mirror function B/W W/B | LCD screen 5″ | Portable/fixed<br>It can be used as the magnifying loupe mobile or fixed support<br>Foldable handle | Not allow | The product itself<br>Not included controller |
| E-Bot Enlarger and video magnifier portable | OCR<br>Plays through voice synthesizer<br>Zoom in/out<br>Contrast level adjustment<br>Wireless network | Contrast level adjust | Allows compact structure<br>Weighs 2 kg | Portable/fixed | Internet connectivity integration with mobile devices and computers<br>Required installing an app on the mobile device | Using a remote control that comes with the product, the E-bot ADV |
| E-Bot Pro Portable video magnifier | OCR<br>Voice synthesizer<br>Magnifying loupe<br>Zoom in/out of the image, text, and setting background colors<br>Wireless own channel<br>Allows image capture and storage on the memory card in JPG or TXT format | Back-ground color adjust | It has about 3 kg<br>It can be folded and compact | Portable/fixed | Connects through wireless<br>Compatible with mobile devices<br>The user can adjust content by gestures on the screen<br>Connecting to computer through USB and HDMI | Joystick controller<br>Camera control through touch screen |

*Source* The authors (2016)

From the analysis of aid products to improve the quality of life and accessibility to visual content for people with low vision, we find three assistive products with control capabilities that allow the user to adjust the visual information according to your needs. These products allow: extend, modify colors, adjust the color contrast, translate the text content or an image by OCR technology through speech synthesizers. Also all products allow mobility and enable compression to facilitate transport.

The integration with other technologies allows the user to connect your assistive product with tablets and computers, and even save the resulting text file of the image scan to a memory card. Files can be saved like an image or text formats for further editing.

Models 2 and 3 allow the OCR decoding, which enables the translation of the content in the form of voice synthesizing. The auto focus capacity of the first model presented and its practicality control with integrated controllers in the own product structure favors mobility because its weight and small size is different compared to the other.

## 5 Conclusions

This paper aimed to compare the characteristics of the main equipment for the accessibility of information for the person with low vision. Through comparative analysis about fixed magnifiers video, portable and magnifying loupes, demonstrated the major contribution of each product to aid.

The three case studies presented in this paper have important features that help people with low vision in the expansion of information, recognition of visual content, color distinction, integration with other technologies, differentiated functionality and possibility of mobility.

The electronic magnifying glass 'Candy 5 HD II' functions as video magnifier and facilitates mobility because users can carry by hand, has less weight to other models presented and drivers engaged in its own structure. The main feature is the fact of being portable, but also allows use in fixed support. It has a mirror function, high definition, expanding capacity by up to 22 times, color modes B/W (black and white)—W/B (white and black) and autofocus. However, this product does not allow integration with other technologies, which is a feature of E-Bot and E-Pro Bot equipment.

E-Bot and E-Bot Pro enable background color adjustment and contrast level, but not P/B and B/P. However, allow connection to wireless network and own network channel and also has OCR technology. Accompanying controllers, since it does not have them in the own product structure. The E-Bot Pro allows for saving captured files in JPG and TXT in memory card system and the E-Bot does not allow.

Thus, this paper reflects the importance of designers and engineers in the development of AT that have most of these characteristics and can in one product enabling these different types of controls and settings for the user, because we observed in the products analyzed the presence of similar features, but some features differentiated from each other.

AT should favor autonomy, mobility and improve the residual vision of the subjects with low vision, stimulating their ability to recognize colors, textures, contrasts and allowing these people to make use of assistive products as aid for recognition of information not only content of books, magazines or instructional material, but also the content of their surroundings, such as plates, bus routes and even in everyday situations, such as self-makeup in the mirror.

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# Design of a Tactile Map: An Assistive Product for the Visually Impaired

**Sabrina Talita de Oliveira, Katsuk Suemitsu and Maria Lucia Leite Ribeiro Okimoto**

**Abstract** Assistive Products that promote the learning of spatial mobility, route guidance and selection of destinations, can favor the independence and quality of life of blind people or with low vision. This paper presents the design process of a tactile map to assist in teaching the discipline of mobility and spatial orientation for blind and low vision people. The tactile map is an assistive product that aids in route selection and location of buildings and public spaces. Such a map has the different blocks through different textures with different reliefs. The project uses the methodology for development of assistive technologies aimed at accessibility and inclusion of people with disabilities. The design process included needs data collection with a teacher of mobility and spatial orientation discipline. Later, with the objective to meet the requirements shown in the research, the researches elaborated sketches and alternatives. After this step, the tactile map was selected as the best option due to costs and resistance through 3D printing technology. The validation of the product will occur with visual impaired users who attend the discipline of mobility in the Blind Institute, located in the state of Parana, Brazil. The product generated can assist the institute's teachers to explain the location of each building, street or public place with the help of differentiation through tactile textures.

**Keyword** Assistive technology · Tactile map · Blind · Low vision

## 1 Introduction

The basic concepts of orientation and mobility (OM) is essential to visually impaired people translocate safely and efficiently through the development of the senses, among which for specific location action commonly is used tact.

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To move from one point to another, more than know routes, you need orientation to the destination and thus build a mental map. Teachers that work OM discipline with this group of people can use tactile maps to define reference points. These maps can be done through artisanal lr industrial methods but it is important to make the student with blindness or low vision[1] trace the path to their operation and rebuilds his/her space [2].

Assistive technology is an area of knowledge (interdisciplinary) involving the development of products, resources, methodologies, strategies, practices and services that aim to promote functionality, activity and participation of persons with disabilities or reduced mobility, in order to improve the autonomy, independence, quality of life and social inclusion [3].

Assistive technology is divided into 11 categories, which are:

- Aid for daily living;
- Augmentative communication (additional) and alternative;
- Accessibility features to the computer;
- Environmental control systems;
- Architectural designs for accessibility;
- Orthotics and prosthetics;
- Postural adaptation;
- Mobility aid;
- Aids for the blind or with low vision;
- Aid for deaf or hearing loss;
- Adaptations in vehicles.

In this research, the developed project is classified as a mobility aid. Given the above, this paper presents a space guidance system entitled of a tactile environment map around the Paraná Institute of the Blind (PIC), an aid product to teach the discipline of mobility for the blind and people with low vision.

The methodological procedure follows the steps: inspiration, ideation and implementation [3]. In this paper, first we present a literature review of tactile maps and subsequently demonstrate the design process to assistive product, from inspiration to the 3D modeling.

It also includes the principle of Universal Design which is defined as a way to transform environments, communication, dispositives, products and services so they can be utilized by people of all kinds of capacity, with the widest extension possible [4, 5].

[1]There are two types of visual impairment, caused by diseases, congenital problems, traumatisms or ocular disfunctions: blindness or low vision. Blindness is the total lost of vision, but it may have some vestige of perception of light. Low vision is when there is difficulty to see near and/or far beyond the limitation of the front and peripheral visual field, the contrast and color perception. Both of them can not be repaired with conventional ways, as glasses or eye contact [1].

## 2 Methodological Procediments

There are some differences to elaborate mockups or tactile maps. The first on brings the information about volumetric format in a real way, while the second option do the same, but with use of symbolic elements such as dots, lines and surfaces [6]. In both cases, the elements should be clearly represented without harming the haptic reading. In a research with 30 blind people it was noticed that tactile maps need to put in evidence the relationship between the elements, the general environment context, precision, urban characteristics, barriers and intersections [7].

There are preferences related to design, symbology, characteristics and cartographical elements. This assistive products should [7]:

- Offer useful information without causing confusion in users;
- Be easy to read by touch;
- Use symbols that can be easily remembered;
- Have good resistance to use and to represent streets crossroads.

It is not necessary to include superfluous details when there is no space enough and when they can be perceived by the use of white cane, such as ramps, stairs and escalators. Still, places a requirement distance between the members of at least 3 mm [6].

**Table 1** *Source* [6]

| Technique | Digital model | Materials that can be used | Description | Capacity to produce | Limitations |
|---|---|---|---|---|---|
| Laser cutter | 2D | Acrylic sheets, cardboard and wood | Cut into layers that are superposed | Contour | Impossible to print Braille and details in high relief |
| Milling machine | 3D | Wood and other synthetic materials | Sculpt by a mechanical arm | Topography and low relief | Impossible to print Braille and to have furrows with negative angle |
| Deposition of material | 3D | Resin and plaster powder, melted plastic | Deposit resin droplets layer by layer | Any kind of mockup, including Braille, depending on machine´s resolution | Resolution does not allow some details |
| Solidification of material | 3D | Liquid or in powder Resin with some light or laser | Solidify resign with laser or light | Everything with high definition and durability | High cost |

Then, rapid prototyping is presented as a way to produce tactile models, according the criteria above because it can provide resistance and the possibility of incorporate high resolution textures, symbols and texts in Braille [8]. There are four main techniques: one in 2D and three in 3D [9]. The first is the laser cutter which is ideal to represent curve levels, but not to Braille and details in high relief. The second is milling machine that has an mechanic arm that sculpts the material, generally used to topographic forms and low relief. The third is the deposition material laying resin droplets for the production of any map, but the resolution may not present some details. The last one uses resin, in liquid or powder, and a laser beam to produces a material with high-definition and durability, but also much higher costs (Table 1).

The techniques application can be utilized to teach disciplines, as cartography or geography, to perceive works of art and tactile maps for mobility. For this project, we propose to use the technique Deposition of Material to meet necessities of PIC.

## 3 Theoretical Foundation

The product development was based on the methodology of User-Centered Design and with emphasis on Universal Design with the following steps: inspiration, ideation and implementation [3].

Initially, we intend to identify necessities of people with visual impairments. According to a professional of OM discipline from PIC, Lilian Biglia, located in Brazil, a tactile map could be easier to teach her students to learn how to get around from one point to another, beginning familiarization with the surrounding area of the institution.

Later, based on the literature review on tactile maps destinated to the visually impaired, we delimited the design methodology [3]. After the inspiration and the ideation phases, it occurred the implementation step. At first, it was made the bidimensional model in sketches. Then, we were able to generate a 3D model in Sketchup software.

After the digital modeling, we exported the archive from Sketchup to the .DAE format (3D model) that maintains the structural and volumetric properties from the generated geometry. Afterward, we readapted the geometry in MeshLab program and exported to .STL to allow 3D printing. Both of the softwares could be used for free and had free license agreement.

From the prototyping phase, it will be applied a survey (Table 2) with PIC teachers of OM discipline to check if the product meets the need that was found

**Table 2** *Source* The authors

| |
|---|
| 1. Do you consider that an assistive product could assist in teaching classes of OM discipline for the visually impaired in Paraná institute for the Blind?<br>( ) Yes ( ) No |
| 2. What are the main difficulties faced by the visually impaired in relation to spatial orientation and location of public places and urban buildings? |
| 3. What is the importance of using an assistive product during class mobility and spatial orientation of blind and low vision? |
| 4. What would you like that were stated in on a tactile map? |
| 5. If you could make use of a tactile map that would help in class mobility with visually impaired, select the features that are important include this assistive product:<br>( ) Blocks and streets<br>( ) Pictograms in relief differentiating blocks<br>( ) Different textures in relief differentiating blocks (each block with a different texture)<br>( ) Marking the sidewalks, the presence of directional floor and alert, simulating the route to the user<br>( ) Blocks in high relief<br>( ) intaglio streets<br>( ) Sidewalks embossed with greater gap compared to the streets<br>( ) Relief of pedestrian paths to traverse the streets<br>( ) lndicative tactile traffic lights<br>( ) Explanatory caption of Tactile surfaces (textures explanation of what each one refers) |
| 6 What a height of unevenness/reliefs and low reliefs that you consider interesting to think when the design of a tactile map? Please answer based on the minimum height required for differentiation of streets/sidewaIks/buildings through the sense of touch by people with blindness or low vision |

before. We also intend to verify the main difficulties by the users related to the spatial learning and memorizing process, such as location of buildings, streets, public constructions. And, finally, to discover if the tactile map helps as a facilitator in OM education to visual impaired people. The idea is to enrich the prototype and adjust it until develop the final product.

With three dimensional printed version, after the Survey application (Table 3) with PIC teachers and the pilot test with students with blindness and low vision, we will enter in Validation phase of Assistive Technology.

**Table 3** *Source* The authors

| |
|---|
| 1. Do you consider that this tactile map would assist in teaching classes to mobility and spatiaI orientation for the visually impaired in Paraná Institute for the Blind?<br>( ) Yes ( ) No |
| 2. Do you consider that the pictograms used to distinguish the most important buildings of each court favor the memorization and the location of each building?<br>( ) Yes ( ) No |
| 3. Do you consider that the pictograms had a significant design that is associated with each building?<br>( ) Yes ( ) No |
| 4. Do you consider that the reliefs or unevenness are suitable for tactile differentiation: blocks, buildings, streets and pictograms?<br>( ) Yes ( ) No |
| 5. You would use this tactile map for mobility and spatial orientation in their day-to-day?<br>( ) Yes ( ) No |
| 6. Recommend suggestions for improvement of this tactile map (if deemed necessary) |

# 4 Results and Discussions

The necessities were gathered in two reunions with Lilian Biglia from OM discipline of OM. The PIC teacher had asked for a tactile map or mockup to serve as support material in initial classes so her students could develop the ability to move between places with autonomy and independence. In that way, it was determined the importance to elaborate a product that could represent in three dimensional format the surroundings of PIC with courts and streets differences and main buildings representation. Then, it was chosen the tactile map due to its resistance and low costs.

Based on images from Google Earth, we started to draw the tactile map in Sketch Up program (student version). The established scales were within the measure limit (20 × 10 × 5 cm) for 3D printing by deposition technique material, the Federal Technological University of Paraná.

## *4.1 Inspiration*

The project modelling followed the requirements found [6, 7] to seek precision and clarity in the information is presentation. In this way, we used symbols that may be easy to remember, distinct and read, with simple shapes and sturdy materials. We also present streets and intersections that separates the courts.

## 4.2 Ideation

The drawn pictograms on each building of the courts have similarity with the widespread used in traffic signals and interfaces in Brazil. Each of the symbols were made by the authors with filled forms and few elements for easy recognition and distinction, as envisaged by NBR 2050—brazilian normative which deals with the accessibility criteria for urban spaces and signaling systems (Fig. 1).

We have highlighted buildings that could be useful in their routine, such as: PIC, supermarket, fast food establishment, hotels, restaurants, dental offices, fitness gym, pharmacy, beauty salon, school, bakery and shopping mall (Table 4).

## 4.3 Implementation

After the structural drawing, we exported files to Sketchup in .DAE format to preserve its properties of 3D model. Then we used it in MeshMixer to correct the surface, repair occlusions and export to .STL format to finally print it (Fig. 2).

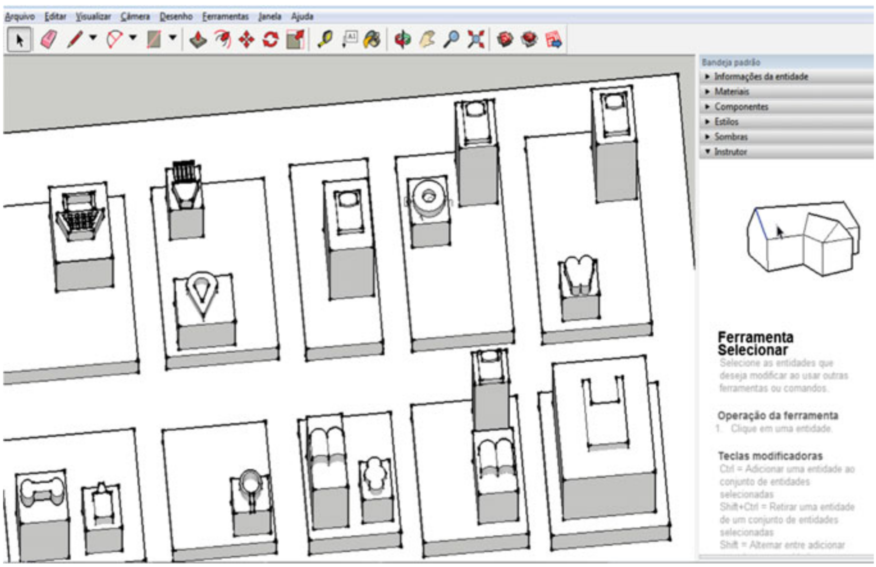


**Fig. 1** *Source* The authors

**Table 4** *Source* The authors

| Places | Simplified pictograms |
|---|---|
| PIC | Symbol of point of arrival that is used in conventional digital maps |
| Supermarket | Shopping cart |
| Fast food establishment | French fries |
| Hotel | Bed |
| Restaurant | Plate |
| Dental office | Tooth |
| Fitness gym | Dumbbell |
| Pharmacy | Medicine bottle |
| School | Mirror |
| Bakery | Bread |
| Shopping mall | Shopping bag |

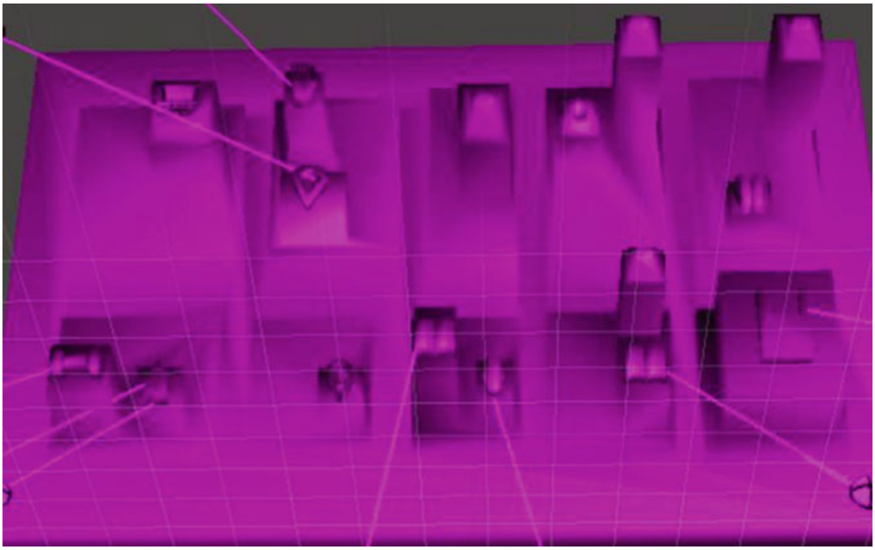

**Fig. 2** *Source* The authors

## 5 Conclusions

This article had the objective to develop a design process of a tactile map that can be affordable, easy to prototype and resistant in its final form. The product should be utilized as a material support in OM lessons at PIC. The needs assessment identified that such assistive technology could help the didactic and pedagogical activities to develop in visual impaired students the ability to dislocate between different places. As we mentioned before, the map should be felt through the sense of touch with relevant details of PIC surroundings that are useful in the user's routine.

To meet the requirements and achieve a concept of the product, we developed a code system based on symbols that may be recognized from its reliefs through the touch by users. In that way, a group of embossed pictograms has been defined to facilitate the differentiation of buildings and facilitate its memorization.

The next stage of this research consists in apply questionnaires proposed in Tables 2 and 3 and the pilot test of the prototype to measure the utility of the product to blind and low vision students. Thus, we can analyse if the prototype can be improved and adjusted to help teachers in OM classes.

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# Part IX
# Innovative Design

# Innovative Approaches and Verification in the Design of Flower Beds to Support Horticultural Therapy Classes

**Meng-Cong Zheng**

**Abstract** Horticultural therapy cannot only improve an elderly emotional and cognitive functions, but also leads to more social participation and better overall health. In this study, the "House of Love", a private nursing home in Taipei, had been the research base. This study found out, that current horticultural classes heavily rely on teacher-centric and volunteer staff assisted curricula often not considering the specific physical limitations elderly usually face in handling gardening tools and flower beds. Our new design "Elderly Green" took the special requirements of horticultural classes in consideration, providing for a maximum of flexibility under varying conditions by modularizing the flower bed. It allowed the elderly participants to move around and do their gardening in a more comfortable and less strenuous manner. This centripetal flower bed design concept increases interaction among the elderly, and reduces nursing manpower needs while improving equally distributed care for each participant during class time.

**Keywords** Flower beds design · Horticultural therapy · Map design · Design for the elderly

## 1 Introduction

Taiwan has already stepped into an aging society. Even though large assisted living facilities provide care services for the elderly, most of the elderly do not want to move into nursing homes because the perceived lifestyle at these facilities is rather foreign to them. "Aging in place" is a concept first originated from Northern Europe during the 1960s. The goal at the time was to care for the elderly with resources that are native to them so they could age in an environment that is familiar to their culture, which would give them the holistic care and independence that they

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deserve. On the other hand, most nursing homes would limit lifestyle choices and social functions, which may damage their mental health and self-respect, which resulted in deterioration of their body and mind [1]. The goal of this concept was to fulfill the native's needs with domestic goods and services, which would require community-like facilities to build a long term care system. Most of the assisted living facilities today in Taiwan are based on community activities to promote interaction amongst the elderlies. Assisted living for individual elders are less common. When daily activities and movements become less convenient for the elders, healthcare-oriented facilities are more important.

Horticultural therapy courses stimulate emotions, boost activity levels, increase muscle relaxation, promote confidence and knowledge, and reduce stress and fear through human-to-plant interactions. These courses can promote their sense of responsibility and self-fulfillment through plant care. Planting and learning about botany enhances cognitive capabilities. Group activities in planting and sharing experiences create community opportunities and respect amongst each other, promoting self-esteem. There is an important connection between social participation and environment recognition of the elderly [2, 3]. There is a strong correlation between the elderly's ability to successfully interact with society and the quality of their facilities and surroundings. Their comfort with the surrounding environment and perception of the social interactions significantly aid their ability to integrate into society [4]. In future planning regarding retirement and assisted-living facilities, it is crucial to include horticulture courses. Many studies show obvious mind-body health improvements amongst the elderly who partake in horticulture classes. However, implementing horticulture courses through assisted care and planning in these facilities are not enough. We need to consider an elder's health condition, activity level, and physical ability in gardening tools and classes in order to effectively implement communication and activity in their curriculum.

This study investigates facilities that have implemented horticulture classes in their treatment. Through qualitative interviews and observation records, understanding the different types of gardening, facility deployment, and gardening treatment details and execution, the studies reveal the problems and conditions associated with these horticulture classes. Follow-ups that occur after this study will also focus on the duration of these classes; understanding the effectiveness of horticulture classes based on its duration will be helpful for future class design and planning.

## 2 Methodology

This study will use "House of Love", a private nursing home as a base. "House of Love" is awarded for excellence of large organization of a total of 250 beds by the Ministry of Home Affairs and Taipei City Hall. "House of Love" was established in 1923, originally founded for the elderly, people with no assistance, the sick, and the homeless. "House of Love" is also the best long term care center in Taipei that focuses on treatment of the body and mind. Through this study, "House of Love" has records of long-term observation, with focus on cases with participation of these horticulture classes, and execution of financial, tools, revenue management, and studies of these classes. This study is carried out in three sections. The first section focuses on investigating elders who participated in horticulture classes. These observations records are revealed in the three classes below:

- Observation One (Group Activity): Class One
  - Flower beds with sitting areas
  - The elderly with dementia and/or ambulatory
  - Nine elders, one teacher, one social worker, and three volunteers
- Observation One (Group Activity): Class Two
  - Operating area
  - The elderly in wheelchair and/or ambulatory
  - Total of 13 Elders (Nine in wheelchair, four ambulatory), one teacher, one social worker, and seven volunteers
- Observation One (Group Activity): Class Three
  - Low floral display area in the back of garden
  - The elderly on lower treatment
  - Total of eight elders, one teacher, one social worker, and ten volunteers (Figs. 1, 2, 3)

Section two focuses on a design proposal of gardening tools Section three uses the post-designed tools in class in practical assessment, further observing the proposal of section two.

- Observation Two (Inspection Unit)
  - Class location: Side exit of the main building in the plaza
  - Elder group: Currently in wheelchair
  - Class Participation: Five elders, one teacher, no social workers, and no volunteer

**Fig. 1** Observation one (group activity): class one

**Fig. 2** Observation one (group activity): class two

**Fig. 3** Observation one (group activity): class three

This study is based on behavioral observation and post-occupancy evaluation. We hope the result would combine gardening therapy and class design in an amicable environment for elders.

## 3 Results

There are more elders with staring into space and resting behavior in class two out of the three classes that were administered. Even though class two has a longer duration, there is no increase of time between the interaction of plants and elders. Furthermore, elders in class two have at the highest, a 39.47 % increase time duration to observe others out of the three classes. The observation of videography reveals that the unequal attention from instructors causes the unattended elders to look around at other elders in boredom (Fig. 4).

In these horticulture classes, the instructor points out that sedentary positions are more suitable for gardening activities that are longer in duration, which can prevent fatigue from stooping or repetitive movements. Compared to classes one and three, class two has three gardening platforms, providing more assistance during gardening. The design of the operating platforms makes it easier for elders to reach, which makes it a more suitable platform for elders to use. On the other hand, there is on average a high discrepancy between dominant and non-dominant hand users in gardening work in class two; this is one area where the design of the platform can improve. Moreover, observations of the three classes reveal that elders who use

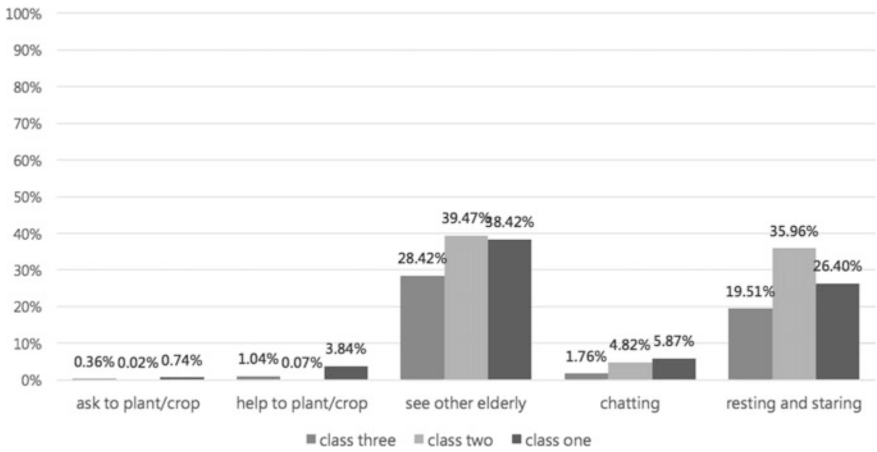


**Fig. 4** Intensity of elder interaction in horticulture class

tools use their dominant hand 32.62 % of the time more than their non-dominant hand, while elders who use their bare hands use their dominant hand only 17.31 % of the time more than their non-dominant hand. From these observations we also know that elders more frequently use tools to work than to use bare hands to work with soil and plants. To give a more comprehensive effect of these horticulture activities, this study will also focus on the design proposals of gardening tools and features.

Moreover, staring into space and resting behavior are the highest in class two out of the three classes that were administered. When instructors are unavailable to attend to an elder, this elder ends up staring into space because he/she is confused about next steps. Observations also reveal that instructors, volunteers, and social workers on average spend the most time assisting elders in class two. The purpose of these horticulture classes is for elders to achieve the therapeutic effect of horticulture classes through finishing class experiments on their own in. Over-guidance from instructors or volunteers could decrease the opportunity for elders to work on their own. One of the 13 elders in class two had much less attendance from instructors and workers. Last, observations from class two reveal that the tools from class two, compared to the available flower at the center of the plaza, is associated with higher mobility which can easily accompany with other classes, even in a class with nine elders in wheelchair. Therefore, we can use the floral platform as a base, and factor in the age of elders, as a template for any future gardening tool design.

### *3.1 Horticultural Flower Bed Design Concerns and Conditions*

These are the three most common problems that occur in gardening work amongst the elders during the first investigation:

- Bad Posture: The tools that were used affected a lot of postures in classes. Inadequate tools encourage poor posture in elders, which offsets the therapeutic benefits of horticulture class.
- Lack of Classroom Interaction: In addition to reducing the aging of body function, horticulture classes also stimulate interactions between the elderly. From these observations, staring-into-space and resting behaviors take up a large percentage of class interaction. Helping and sharing interactions amongst elders will be a critical design criterion for flower bed platforms.
- Uneven Care Amongst Elders: Teachers and workers, other than the main instructor, also need to focus on the situation of all elders, which further increases the burden on the teachers and workers. Therefore, most of these horticultural classes will arrange volunteers to help. However, an oversupply of volunteers will cause uneven care amongst the elders, and reduce their independence to work in these activities. A goal of future flower bed design should take into account the volunteer-to-elder ratio.

Based on all of the above conditions and concerns on the sizing and interaction factors, we have designed an integrated wooden flower bed. The flower bed is a trapezoidal desk, which allows everyone to gather around in a circle, and makes it more convenient for the instructor to communicate with the elderly (Fig. 5).

## 4 Discussions

This discussion takes the new design of the flower desk into the curriculum. This class has a total of five participants, including four women, one man, where three of them are in wheelchairs. The five new flower desks are arranged radially, with an opening for the instructor to freely walk in and out of the circle. The students now sit equidistant from the teacher in a circle (Figs. 6, 7).

In the test group during the horticulture class, the elderly use dominants hands 26.30 % of the time, non dominant hands 17.58 % of the time, and both hands 12.32 % of the time when using bare hands. Compared to the control group, the test group have a much higher usage of hands in all three categories, especially in the non-dominant hands usage. The test group uses bare hands 56.21 % of the class, which is much higher than the control group of in class two of 25.28 %. As a result, this new flower bed design stimulates both hand usage and balance in the elderly. From flipping soil to digging a hole to placing a seed to burying soil, elders all

**Fig. 5** Prototype of flower beds

**Fig. 6** Usage scenarios of test group

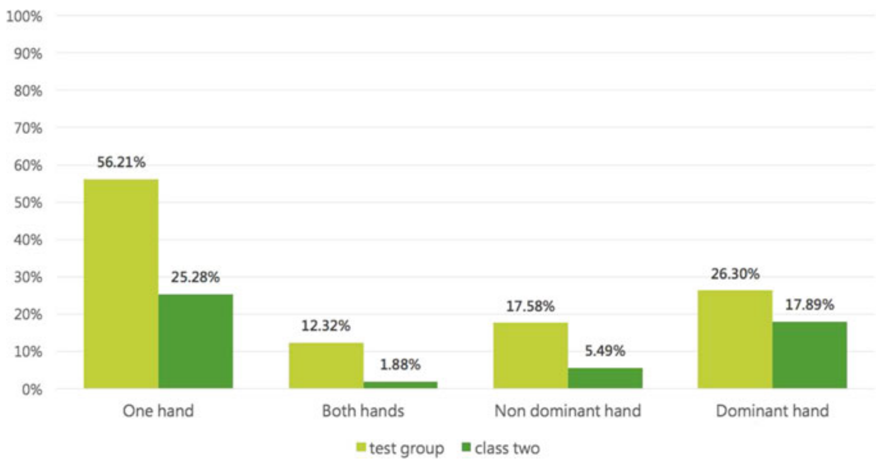


**Fig. 7** Average percentage of time working with bare hands

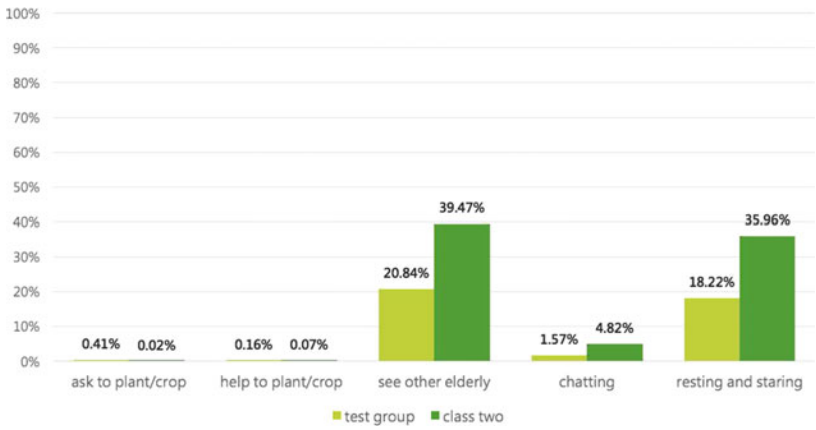


**Fig. 8** Interaction of the elders in class in percentage

fulfilled the hand movement goals. It could be the design of "Elder Green" that allow elders to feel more intimate toward the product (Fig. 8).

The percentage of the time of the test group, where the elderly spent staring into space or resting, took up 18.22 %, which is significantly lower than the control group of class two at 35.96 %. The elders in the control group spent a lot more time on planting activities, much less time in idle. We observed that the elderly were occupied not because of instructor supervision, but because they were immersed in their tasks which happened to be under instructor supervision. This means that "Elder Green" the new flower bed, also causes students to be more interested in classrooms.

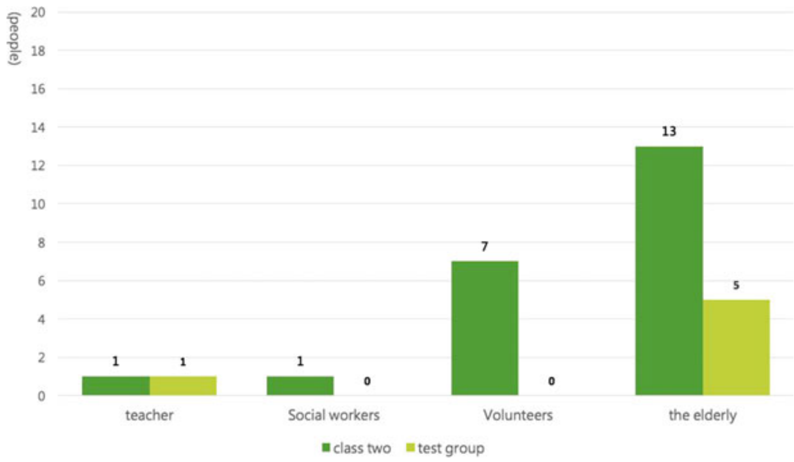


**Fig. 9** The relationship between the number of instructor and elders

## *4.1 A Comparison Between Pre and Post Design Behavior, Factoring in the Number of Elders*

The control group of class two have a total of 13 participants, accompanied with nine workers and one teacher. The ratio between workers and the elderly is 9:13. After the new and unique design function of the flower bed, in addition professional and garden therapist advisory, the user base of "Elder Green" is set at five, accompanied with one instructor (Fig. 9).

## *4.2 A Comparison of Caregiving to Elders Between the Pre and Post Design*

From the image we learn that the percentage of time where an elder gets verbal instruction in class is 7.19 %, physical instruction is 6.46 %, and the average time where instructor demonstrate for an elder is 57.4 s, at 1.97 % of class time (Fig. 10).

Compared to class two, the elderly in test group is much more enthusiastic about the curriculum, significantly reduces any distraction from other volunteers. Volunteer demonstrations have also decreased. The goal of horticultural classes is for the elderly to find therapeutic effect when working independently. In the past, the instructor or volunteer often had to demonstrate in place of an elder, which takes time away the elder to work on his own. Implementation "Elder Green" in the new curriculum will have positive effect on horticultural activities.

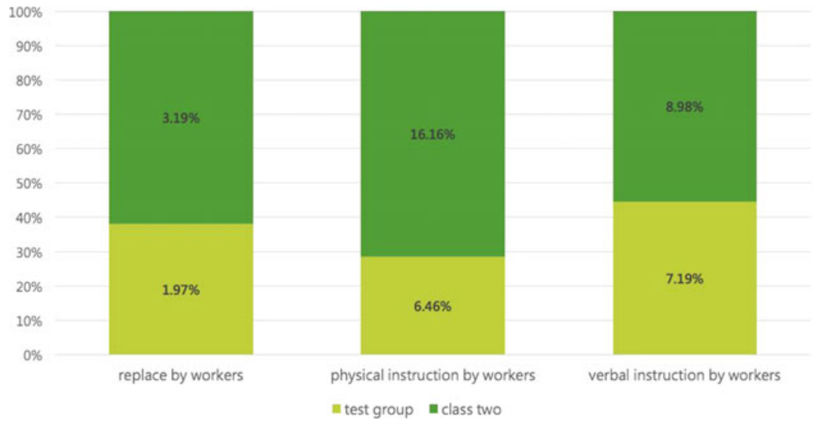


**Fig. 10** The percentage of time when an elder receives care

## 4.3 *Comparison of Pre and Post Design, Factoring Workers to Elder Interaction*

Even though there were 13 elders to 9 volunteers in the control group of class two, the attention on all the elderly were unequal. On the other hand, there are only one instructor for every five elders, the elders of test group have a much even guidance and care from the volunteers and instructor. Regardless of whether it was due to increased mental stimulation or physical exercise, the test group had a much better experience than the control group in both categories. This reveals of how the instructor-centric class mode of "Elder Green" brings to the table. More than creating a balance of instruction to each student, "Elder Green" helps the elders with fewer instructors and volunteers, conducting a more quality fulfilling class (Figs. 11, 12).

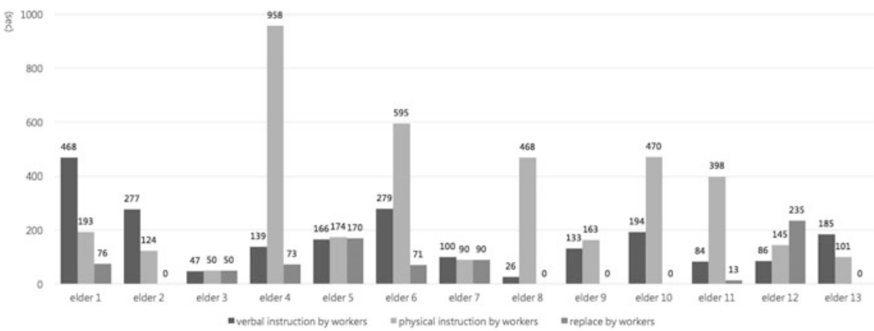


**Fig. 11** The relationship of class two control group between workers and elders

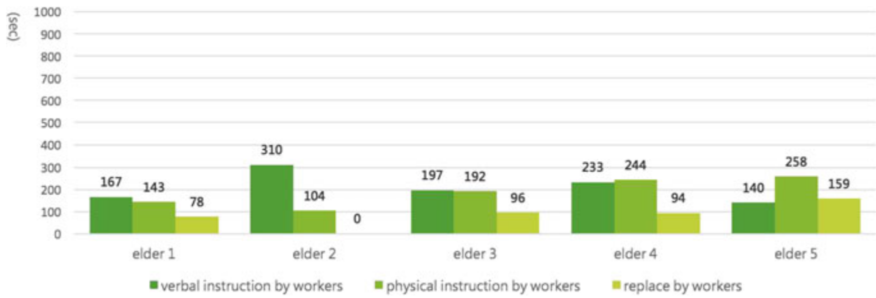


**Fig. 12** Relationship of the test group between workers and elders

## 5 Conclusions

The flower bed of "Elder Green" allows soil depth of at least 15 cm. From research and studies, the height of the space under the desk is set at 62 cm which is a one-size-fit-all for elders of different height and wheelchair users. The previous designs of "Elder Green" did not consider any drainage issues. The previous design could not support and protect the plants in the flower bed under continuous watering or rain showers for plants that were grown outdoors. This study designs a system that would not require any tubing for drainage, which can prevent any potential damages to the tubing, create space and convenience for elders to use the desk. The specification for the different basin choices are available in the market; one just need to follow the water path direction, poke a hole, which makes future replacements easier (Fig. 13).


**Fig. 13** Different type of "elder green" Arrangements

**Table 1** Design specification for flower beds

| Specification | Explanation |
|---|---|
| Measurements | Contain at least 15 cm deep of soil |
| | Height from floor to desk is 62 cm |
| | The desk height allows a wide range of sitting positions |
| | The desk depth allows a wide range of sitting positions |
| Configuration | With good drainage |
| | Fits existing basins, which makes future replacement easier |
| Appearance and material | Have modular design based on different class arrangement |
| | If you choose wood as your material, make sure to first coat it with a special coating |
| Function | Storage needs for relevant props |
| | The design can be used as an armrest for sitting down and standing up |
| | Wheel lock as an add-on to prevent slipping |

"Elder Green" can be arranged in different forms based on the number of participants and the purpose of the horticulture class. These flower beds can be arranged in different shapes as the number of desk increase. The water beds are mostly made out of wood. The many layers of the protective wooden oil create a warm and moist feeling when touching the wooden desk. The tools that one would use for this class, such as a hoe, shovel, plant, and etc. can easily place on top of the desk or in the built-in drawer, which allows an elder to work seamlessly. Additionally, an elder can use the flower bed desk as a hand-holder when sitting down or standing up for class. Wheel lock can be installed to make moving arrangements easier on the desk, and to prevent the flower basin from shifting around. The chart below explains the design specifications of the flower bed (Table 1).

The "Elder Green" flower Beds has potential to improve in many aspects. For example, customizable flower platforms can highlight the differences in design. Different types of wooden patterns, wooden colors, and the color of the flower basin are examples of customization. Different horticultural class curriculums, tools for the elderly, combined with different medical aids are all worthy of investigation for the future.

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# A Method for Measuring the Weight of Body Segment Based on Human Model and Body Pressure Distribution

**Fei Fang, Liming Shen, Yuxia Chen and Yuding Zhu**

**Abstract** The weight of each human body segment is a very important parameter for zonal mattress design; it directly affects the design quality and lying comfort of zonal mattress. However, such researches or a method for measuring the weight of body segment to a living person has not been founded before. This paper explored a method for measuring the weight of body segment based on human model and body pressure distribution. Combined with three kinds of somatotypes, overweight, normal and underweight, using six different weight proportions of the human model, the pressure distribution experiment was carried out on a spring mattress and the regression model was constructed between the weight of each body segment and the force on human model. According to the mathematic model, the force of fifteen subjects (including seven females and eight males) on the same mattress and human anthropometrical measurement, the actual weight of each body segment could be calculated. The error analyzing shows that the mean relative error of the measurement results of three somatotypes was 2.4 %. The error may be caused by the anthropometric measurement of subjects and the experimental instrument. The error range could be accepted and the method can be applied in the practice of mattress design.

**Keywords** Anthropometry · Human model · Body pressure distribution · Weight of body segment · Mattress design

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## 1 Introduction

The weight of each body segment is a basic parameter of human sports biomechanics researches. In the recent century, researchers from all over the world have studied on human inertial parameters and made some breakthroughs. In general, the research methods could be classified to three kinds, corpse measurement, living measurement and mathematical model measurement.

Corpse research method aims to measure inertial parameters of each segment by autopsy. From 1860 when Harless dissected two male corpses [1], to 1970s, nearly fifty corpses were dissected. The weights of each segment were measured and the majority of them were male adults. Due to the possible huge difference between dead and living tissues, and the number of corpses studied by each researcher, the results might be limited and affected.

Living measurement includes gravity plate method, water immersion, combination of anthropometry and X ray, radioisotope method and CT method. The early gravity plate method can only measure the location of two-dimension general gravity center in different body postures, and the measuring equipment has developed from gravity plate and platform scale to transmitter and digital indicator. Water immersion method of acquiring the quality, according to the principle of Archimedes, is to determine the volume by the displacement of human body segments and then multiplied with the human average density. In fact, the density of each human body segment is not the same and it affects the measurement accuracy of the inertial parameters of human body segments. The method combination of anthropometry and X ray was used by Songjing in 1958 [2, 3]. The human body was divided into fifteen segments which then were simplified to much geometry and X ray was used to determine muscle and bone volumes. The weight of each segment was determined by the known muscle and bone density multiplied the volume respectively. Heymsfield and Brooks [4, 5] have studied the relationship between CT number and weight and density of human body segments. Ackland [6] studied the consistency problem of human segment density using dual energy method. Zheng et al. [7] measured human inertial parameters of one hundred subjects (including 50 males and 50 females) by using CT and CIP (Computerized Image Processing) methods.

Mathematical model method used geometry to simulate human segments to obtain the parameters. Harless suggested using geometry simulating human segments, such as simulating head to ellipse sphere and truck to ellipse cylinder. The characteristics of these models were simplifying human body structure and function [1]. In 1975 the national technical information service published studies of the human body inertia properties reports. According to the variable regression equation and the weight, human segment rotational inertial parameters could be calculated, that is Chandler parameters [8].

The paper aims to investigate a method to measure the weight of human body segments by using human model and body pressure distribution. By testing pressure distribution of different weights of human model on the mattress, a regression relationship models the force value and the force value and actual weight of each body segment could be constructed. According to the regression model, with known force values of subjects by body pressure distribution testing, the weight of human body segments could be calculated.

## 2 Materials and Methods

The human model used in the experiment was made by metal. According to China standard "GB 10000-88 Human dimensions of Chinese adults", the data of the fiftieth percentile adult men was chosen to design the model, with the height of 168 cm and the weight of 59 kg [9]. Based on the theory of human biomechanics and anatomy, the segments of the model included head and neck, upper back, lumbar, pelvic, thigh, calf and feet.

Six different levels of the weight were adopted in the experiment. According to the weight distribution data, Chinese standard "GB/T 17245-2004 human inertia parameters of adults", the weights of each segment of body with 59 kg were calculated [10], as Table 1 shows. Based on experience, the differences of human body weight were focused on upper back, lumbar, pelvic and thigh. Adjust the weights of each segment of six levels and sand bags were used in weight allocation. Different weights of sand were put in the bags and then were attached to the segments of human model.

15 subjects participated in the test, including 8 females and 7 males. According to the BMI (BMI, Body mass index), the subjects were separated into three groups, underweight, normal and overweight. The human body was also divided into seven segments, just as the human model. The longitudinal dimension parameters were acquired through anthropometry, providing basis for analysis of body pressure distribution parameters.

A medium firmness spring mattress, provided by a mattress manufacturer in local, was chosen in the experiment. The parameters of wire diameter, circle

**Table 1** Body weight distribution of human model

| Human model segments | The total weight of human model (kg) | | | | | |
|---|---|---|---|---|---|---|
| | A. 45 kg | B. 50 kg | C. 55 kg | D. 59 kg | E. 65 kg | F. 70 kg |
| Head and neck | 4.6 | 4.7 | 4.9 | 5.09 | 5.2 | 5.3 |
| Upper back | 6.8 | 7.8 | 9 | 10.4 | 12 | 13.5 |
| Lumbar | 2.5 | 2.84 | 3.2 | 3.9 | 4.5 | 5 |
| Pelvic | 8.4 | 9 | 11 | 11.7 | 14.34 | 16.02 |
| Thigh | 7 | 8 | 8.2 | 8.37 | 8.6 | 8.8 |
| Calf | 1.6 | 1.8 | 2 | 2.17 | 2.3 | 2.5 |
| Feet | 0.82 | 0.83 | 0.85 | 0.87 | 0.88 | 0.89 |
| Upper arm | 1.1 | 1.2 | 1.3 | 1.43 | 1.5 | 1.6 |
| Forearm | 0.8 | 1 | 1.1 | 1.12 | 1.2 | 1.3 |

diameter and lap were 2.0, 60 and 6 mm respectively. The experiments were carried out in Ergonomics lab of Nanjing Forestry University. The temperature and humidity were (23 ± 2) °C and (50 ± 5) %. Due to the limitation of the human model, supine posture was the only posture used in the experiment. When lying on the mattress in supine posture, subjects were asked to be relaxed with arms aside by the body. Subjects should wear loose and comfortable clothes, without any sharp or prominent decorations and belongings.

The pressure distribution system was used to acquire the force value. The sensor pad contained 34 * 34 or 1156 one-centimeter square individual pressure sensing cells capable of providing the pressure distribution of whatever was put on the pad.

## 3 Results

By pressure distribution testing human model with different levels of weight, the force could be acquired and regression analysis was made to construct the relationship model between the force value and the actual weight of each segment (Tables 2, 3, 4, 5, 6).

**Table 2** The force value of each segment of human model

| Human model segments | The force of each segment of human model (kg) | | | | | |
|---|---|---|---|---|---|---|
| | A. 45 kg | B. 50 kg | C. 55 kg | D. 59 kg | E. 65 kg | F. 70 kg |
| Head and neck | 4.44 | 5.25 | 5.75 | 4.83 | 4.76 | 4.86 |
| Upper back | 9.57 | 10.08 | 12.88 | 12.37 | 15.5 | 16.79 |
| Lumbar | 1.11 | 1.22 | 3.06 | 3.68 | 4.04 | 5.72 |
| Pelvic | 9.87 | 7.98 | 12.14 | 13.01 | 15.39 | 15.92 |
| Thigh | 15.79 | 16.99 | 16.61 | 18.03 | 17.53 | 18.71 |
| Calf | 4.3 | 4.22 | 5.38 | 6.72 | 6.35 | 7.42 |
| Feet | 0.33 | 0.05 | 0.06 | 0.43 | 0.31 | 0.27 |
| Total | 45.41 | 45.78 | 55.95 | 59.07 | 63.88 | 69.69 |

**Table 3** The regression relationship between force and actual weight of each segment of human model

| Human model segments | The regression relationship between force (X) and actual weight (Y) of each segment | Correlation coefficient |
|---|---|---|
| Head and neck | $y = -0.03371\times + 5.13294$ | −0.05507 |
| Upper back | $y = 0.86066\times - 1.15572$ | 0.96989 |
| Lumbar | $y = 0.53358\times + 1.98211$ | 0.90735 |
| Pelvic | $y = 0.91328\times + 0.43241$ | 0.94784 |
| Thigh | $y = 1.08087\times - 2.35044$ | 0.88547 |
| Calf | $y = 0.47823\times + 1.38226$ | 0.95267 |
| Feet | $y = 0.13729\times + 1.68015$ | 0.37676 |
| Total | $y = 0.93967\times + 4.11954$ | 0.9819 |

**Table 4** The calculation of each segment weight of underweight group (kg)

| Human body segments | Subject 1 | Subject 2 | Subject 3 | Subject 4 | Subject 5 |
|---|---|---|---|---|---|
| Head and neck | 4.99 | 4.94 | 4.95 | 4.96 | 4.96 |
| Upper back | 9.21 | 10.44 | 9.80 | 9.40 | 9.78 |
| Lumbar | 2.34 | 3.19 | 2.60 | 2.44 | 2.32 |
| Pelvic | 18.01 | 20.08 | 20.30 | 19.26 | 19.36 |
| Thigh | 3.65 | 4.51 | 4.20 | 3.88 | 3.77 |
| Calf | 2.49 | 2.52 | 2.60 | 2.49 | 2.56 |
| Feet | 7.12 | 7.16 | 7.11 | 7.08 | 7.11 |
| Calculated weight | 47.82 | 52.84 | 51.56 | 49.51 | 49.87 |
| Actual weight | 50 | 51 | 52 | 50 | 50.5 |
| Relative error (%) | 4.36 | 3.61 | 0.84 | 0.97 | 1.25 |

**Table 5** The calculation of each segment weight of normal group (kg)

| Human body segments | Subject 1 | Subject 2 | Subject 3 | Subject 4 | Subject 5 |
|---|---|---|---|---|---|
| Head and neck | 4.86 | 4.95 | 4.91 | 4.93 | 4.95 |
| Upper back | 19.61 | 18.39 | 16.11 | 18.28 | 13.33 |
| Lumbar | 1.79 | 2.83 | 2.93 | 2.04 | 5.19 |
| Pelvic | 30.82 | 23.84 | 18.26 | 20.46 | 16.39 |
| Thigh | 6.11 | 3.38 | 5.18 | 3.72 | 3.10 |
| Calf | 2.56 | 2.90 | 2.60 | 2.89 | 2.78 |
| Feet | 4.16 | 6.84 | 8.18 | 8.34 | 6.48 |
| Calculated weight | 69.91 | 63.13 | 58.17 | 60.65 | 52.22 |
| Actual weight | 68.00 | 62.50 | 59.00 | 57.50 | 50.00 |
| Relative error (%) | 2.81 | 1.01 | 1.40 | 5.47 | 4.44 |

**Table 6** The calculation of each segment weight of overweight group (kg)

| Human body segments | Subject 1 | Subject 2 | Subject 3 | Subject 4 | Subject 5 |
|---|---|---|---|---|---|
| Head and neck | 5.00 | 4.97 | 4.95 | 4.96 | 4.97 |
| Upper back | 20.61 | 21.98 | 21.13 | 20.86 | 20.37 |
| Lumbar | 2.93 | 2.98 | 3.04 | 3.41 | 3.08 |
| Pelvic | 32.92 | 33.88 | 34.76 | 32.22 | 31.02 |
| Thigh | 7.72 | 7.40 | 7.59 | 7.82 | 7.39 |
| Calf | 3.56 | 3.49 | 3.57 | 3.61 | 3.36 |
| Feet | 7.25 | 7.33 | 7.01 | 7.21 | 7.18 |
| Speculated weight | 79.99 | 82.02 | 82.05 | 80.10 | 77.38 |
| Actual weight | 82 | 81.5 | 80 | 81 | 80 |
| Relative error (%) | 2.45 | 0.63 | 2.57 | 1.11 | 3.28 |

## 4 Discussion

The results of the study show that it is possible to measure the weight of human body segments by human model and body pressure distribution methods. There is an error between the calculated weight and the actual total one. In the experiment, a mattress was chosen as a tool. By knowing the weights of each body segment, the elasticity of mattress could be better used in mattress design.

The error could be counted for many reasons, error in anthropometry, experimental equipment error and other factors. In the experiment, anthropometry is the basis of analyzing pressure distribution data of each body segments. Manual measurement was made by choosing the truck bony location. However, for overweight subjects, due to the cover of fat layer, it is not easy to locate the measurement locations, which might lead to the error. The body pressure distribution system is made of a pressure sensor pad and a handle. The transistors in the sensor pad might have a tandem effect under a long duration of loads. So it needs to calibrate the sensor pad in time. After calibration it could be examined by applying a certain force on it and the interference could be avoided. Other factors, such as small change of sleep postures in the experiment and data analysis error might also be avoided.

## 5 Conclusions

This paper explored a method for measuring the weight of body segment based on human model and body pressure distribution. Combined with three kinds of somatotypes, overweight, normal and underweight, using six different weight proportions of the human model, the pressure distribution experiment was carried out on a spring mattress and the regression model was constructed between the weight of each body segment and the force on human model. According to the mathematic model, the force of fifteen subjects (including seven females and eight males) on the same mattress and human anthropometrical measurement, the actual weight of each body segment error of the measurement results of three somatotypes was 2.4 %. The error may be caused by the anthropometric measurement of subjects and the experimental instrument. The error range could be accepted and the method could be applied in the practice of mattress design. The study provides theoretical basis for customized zonal mattress design according to the somatotypes of people.

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# Testing and Evaluation of a New Multitrack Electric Bicycle—A Comparative Study

**Sophie Steinmaßl and Markus Lienkamp**

**Abstract** In this paper, we propose new procedures to test the vehicle dynamics and to proof the usability of a new four-wheeled concept bicycle. We have done this by combining standard tests from the automotive industry and regulations from the bicycle industry. Objective and subjective methods are used to evaluate handling. For the objective evaluation of the vehicle dynamics, standard tests from the automotive industry have been adapted (e.g. steady state circular test, brake test, double lane change task). Approximately ten maneuvers were developed and adjusted, such as the distance from pylons or the speed for multitrack electric bicycles. Additionally, the tests were performed with similar bicycle designs and compared to the new vehicle concept.

**Keywords** Testing · Multitrack electric vehicle · Cargo bike · Product development process · QuadRad

## 1 Introduction

The market for pedal electric bicycles is growing rapidly. So called “cargo bikes” are becoming more important as business vehicles. Multitrack cargo bikes can widen the fields of application for these bicycles by adding more transport capacity and driving stability. However, in the cycling industry, there is no standardized product development process for multitrack electric bicycles. In consequence, there is also no standardized testing procedure to ensure their safety. Since this is an important part of the product development process, new methods have to be developed. Therefore, process models from the automotive industry can be adapted for such vehicle concepts to ensure a successful product development process for the increasing demand.

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## 1.1 State of the Art

**Bicycle Industry**
In the bicycle industry, there is no standardized procedure for testing multitrack vehicle concepts, until now. There are only guidelines for testing bicycle components in terms of strength and stability (DIN EN 14766), but none in terms of driving dynamics and comfort [1]. There are rules which specify the maximum braking distances for mountain bikes, and these distances can be determined through testing.

In contrast to the bicycle industry, extensive testing procedures are performed in the automotive industry.

**Automotive Industry**
Both subjective and objective methods are used to evaluate the performance of a vehicle. Subjective tests are carried out by development engineers or so-called skilled drivers. Objective tests can be done by means of computer simulation or with appropriate measuring equipment. In addition, driving performance tests (closed-loop) and road performance tests (open-loop) are distinguished. In closed-loop experiments, driving dynamics are judged subjectively by the driver, as he controls the vehicle. During open-loop tests, inputs such as, acceleration, steering angle, etc. are determined. The influence of the driver is minimized, the results of the driving tests are highly reproducible. In both tests, the open and closed-loop measurement instruments are used to document the results. The limitations of a vehicle can be determined by carrying out driving tests. In this case starting, braking, steering and cornering behavior are reviewed. Moreover, directional ability and ride comfort are evaluated. Standardized maneuvers and test conditions are described in ISO TC22/SC9 [2].

# 2 Procedure

Before a new vehicle concept can be used by volunteers, internal testing and validation has to be performed by professionals. This implies that the vehicle is brought to its dynamic driving limits and tested under extreme situations. For this purpose, special driving tests have been developed especially for multitrack bicycles. The maneuvers were derived from the automotive industry and adapted accordingly. To validate the results, test runs were carried out with different concept vehicles, including a newly developed concept vehicle which is called “QuadRad”. This innovative concept is verified in everyday life on functional reliability and durability under real conditions.

**Fig. 1** QuadRad, City Shopping Bike, Babboe Big, Babboe City (from *left*)

## 2.1 Vehicle Concepts

The four concept vehicles used are described in detail in the following. This involves single- and multi-track cargo concept bikes (Fig. 1).

The so called “QuadRad” is a type of bicycle with four wheels and electric pedal assistance [3]. The concept integrates high transport capacity, driving comfort and safety as well as low total costs of ownership. The concept vehicle is designed especially for commercial applications and for use in everyday life [3]. The QuadRad is powered by a mid-engine with a power of 250 W and a maximum torque of 70 Nm. In addition to that, the driver is supported up to a speed of 25 km/h from the electric motor, thus the QuadRad does not require registration [4, 5].

The “City Shopping Bike” is a three-wheeled bicycle with two wheels at the rear axle, why it is called Delta. The city shopping bike is especially for use in everyday life, the revenue load is 22 kg. “Babboe Big”, is a so-called tadpole, which means it is a three-wheeled cargo bike with two wheels at the front axle. The concept vehicle can used on the one hand for carriage of goods (payload 100 kg) and on the other hand, children can be seated in the cargo box, which is equipped with a bench and a three-point belt. The “Babboe City” is a single-track version of a cargo bike. Besides loads, one can also transport children with this kind of bicycle. In addition to that, the cargo box is low positioned and stable [6]. The wheel base of this concept vehicle is comparatively large. All values are listed in Table 1.

## 2.2 Experimental Setup

The values generated by open-loop and closed-loop maneuvers allow a comparison of different concept vehicles. This is possible because the rider theoretically has no influence. Moreover measuring devices were used for several tests.

The driving tests are intended to cover the entire range of multitrack bikes. The handling at the speed limit of the vehicle and in extreme situations can be found in the manner described. To recreate everyday use as accurately as possible, some maneuvers had to be driven with different parameters. These include different loading conditions, the selected tires and different road surfaces. According to a

**Table 1** Technical specifications

| Characteristic | Value |
|---|---|
| QuadRad | |
| Wheel base | 1350 mm |
| Wheel track | 730 mm |
| Tyre size | 26 in. |
| Chassis clearance | 153.5 mm |
| Drive concept | Mid-Engine (BLDC) |
| Weight of vehicle | 60 kg |
| Revenue load | 180 kg |
| City Shopping | |
| Wheel base | 1320 mm |
| Wheel track | 635 mm |
| Tyre size | 26 in. |
| Chassis clearance | 140 mm |
| Drive concept | Mechanical |
| Weight of vehicle | 32.5 kg |
| Revenue load | 22 kg |
| Babboe Big | |
| Wheel base | 1360 mm |
| Wheel track | 725 mm |
| Tyre size | 26 in. rear/20 in. front |
| Chassis clearance | 75 mm |
| Drive concept | Mechanical |
| Weight of vehicle | 61 kg |
| Revenue load | 100 kg |
| Babboe City | |
| Wheel base | 2000 mm |
| Wheel track | – |
| Tyre size | 26 in. rear/20 in. front |
| Chassis clearance | 150 mm |
| Drive concept | Mechanical |
| Weight of vehicle | 45.5 kg |
| Revenue load | 80 kg |

survey, most paved or well-developed forest roads are used with bicycles. Based on these results, the tests were carried out on the corresponding roads. Regarding the payload, most people want to transport their daily purchases. An average purchase for daily food weighs, according to own investigations, about 17 kg. In addition there are some concept vehicles with the possibility to transport a child. A child between the age of two and five has an average weight of 17.2 kg [7]. This results in a total weight of 34 kg payload. In order to recognize the limitations of the vehicle, the driving tests must also be driven with maximum payload.

The maneuvers are all performed at constant tire pressure (3.5 bar). The pylon distances were scaled to the size of the cargo bicycles. The experimental setup is shown in the following figures (Figs. 2, 3, 4, 5, 6, 7, 8, 9). Driving direction, position of the pylons and speed are pictured for each maneuver (Fig. 2). Three valid attempts are recommended for each test.

For braking distance and other lengths, the correction function (1) according to DIN EN 14766 must be used [1]:

$$L_{kor} = (v_s/v_m)2 \cdot L_m \tag{1}$$

$L_{kor}$ corrected length
$L_m$ measured length
$v_s$ prescribed test speed
$v_m$ measured test speed

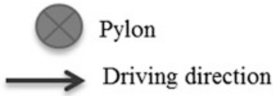



**Fig. 2** Legend—structure of driving maneuver

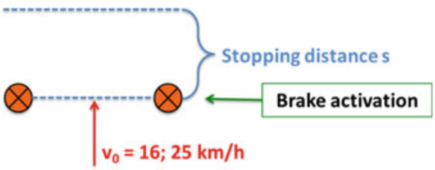



**Fig. 3** Full application of the brake

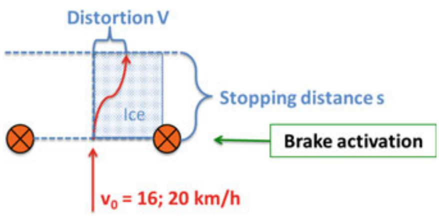



**Fig. 4** μ-split brake activation

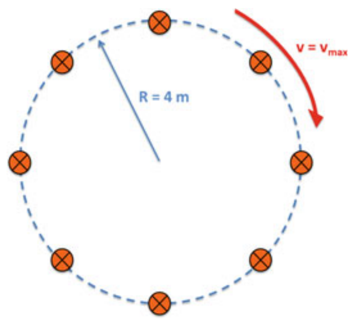



**Fig. 5** Steady-state skidpad testing

**Fig. 6** Figure of eight

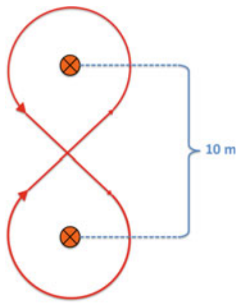



**Fig. 7** Rapid steering input

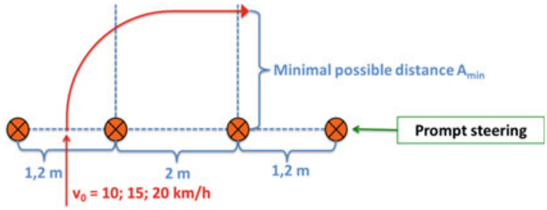
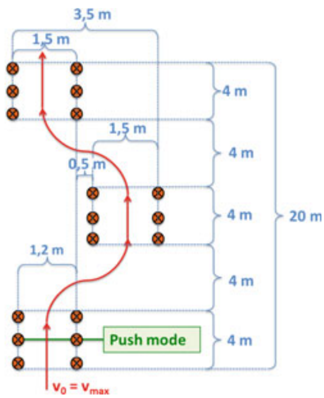



**Fig. 8** Double lane change




A test which shows the full application of the brake (Fig. 3) is essential to ensure driving safety. A typical driving condition for this experiment is the sudden appearance of a barrier, the driver cannot swerve in time. There is a quantitative assessment of the braking system. This is based on DIN EN 14766 for mountain bikes [1]. The specified values in this guideline for braking distances have been shortened to 2/3. When driving straight ahead three brake applications at a speed of 16 and 25 km/h are performed. On a cycle path on the edge of an icy road or a narrow bike path with soft shoulders during braking creates a yaw movement which pulls the vehicle toward the slip proof lane. The reason for this is a braking force imbalance between the right and left brake. In order to determine the distortion

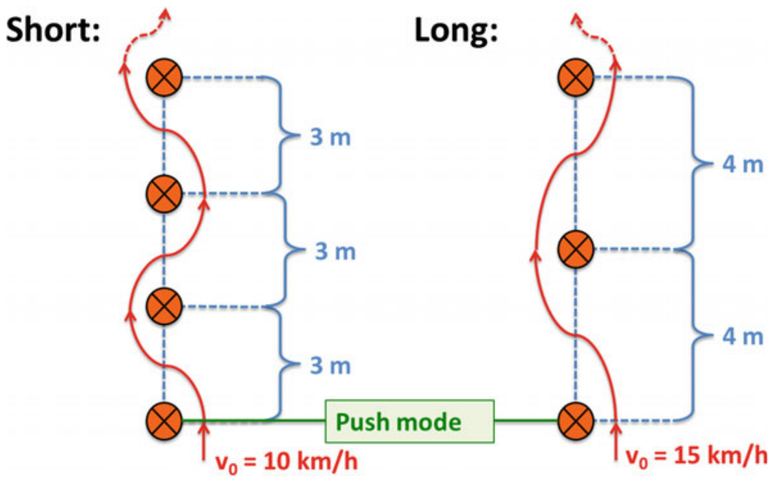



**Fig. 9** Slalom

while braking during the described situation a μ-split brake activation test is performed (Fig. 4).

In the steady-state circular test (Fig. 5) the drivability of multitrack bicycles is judged. In contrast to the steady-state skidpad test in the automotive industry, self-steering behavior is not examined, but rather, which maximum speed and lateral acceleration can be achieved. A circle with a radius of 4 m has to be marked. In addition, the measuring sensors have to be installed in order to determine the lateral acceleration of the concept vehicles. A figure of eight test is a supplement to the other test, to verify the results.

In the automotive industry, the steering input is one of the open-loop driving tests. Nevertheless, in the case of multitrack bicycles, the maneuver is classified into closed-loop driving tests. Due to the tilt behavior by the high center of gravity, the rider plays a major role in such concept vehicles. This experiment examines the tilting behavior and the check ability in strong steering maneuvers. The test is performed at speeds of 10, 15 and 20 km/h and the lowest possible distance is measured (Fig. 7). Using the double lane change (Fig. 8), the tilt tendency of the vehicle is determined at a rapid evasive maneuver and subsequent re-filtering to the lane.

This test is used to evaluate the driving behavior during quick changes in direction. Handling and controllability are examined. Behavior can be assessed at high and low speeds by using a short and a long version of the slalom (Fig. 9). With this maneuver, it can be ascertained as to whether the chassis offers a good compromise between driving safety and comfort. If the suspension designed is too soft, strong sway and rapid loss of control can be expected. If on the other hand, the chassis is designed especially taut, the course will be easy to handle. However, riding comfort would be lower. To apply the test on different multitrack bicycles, compulsory distances are fixed, 3 m for the short and 4 m for the long slalom.

## 3 Results

Subsequently, the results of the driving tests are described.

The weight and in particular the weight distribution of a vehicle affects driving behavior and driving dynamics. The City Shopping bike, weighing approximately 23.5 kg (Table 2) is the lightest bike. In addition, the axle load is predominantly on the rear axle, which can be explained concept due to the triangular 'delta' design. The concept vehicle QuadRad has a stable and, in consequence, heavy rear axle, due to the high payload (180 kg). Babboe Big with tadpole design and a large transport box in the front has correspondingly more weight on the front axle, which can be noticed while steering. Babboe City, the single track vehicle, is most balanced in terms of weight distribution.

Due to the delta design, the City Shopping bike has the smallest turning circle (Table 3). The steering angle of Babboe Big is relatively limited, due to this the turning circle is respectively big. Due to its length, Babboe City has a fairly large turning circle. None of the concept vehicles is equipped with a reverse gear, there for a small turning circle is essential especially for riding in the city.

For the braking test, an allowable stopping distance of 4 m is set at a speed of 25 km/h. Not all concept vehicles have fulfilled this requirement (Table 4). The vehicles Babboe City and Babboe Big have partially exceeded the values, due to the brake system. The shortest stopping distance was achieved with 2.50 m with the QuadRad. The positive results with this concept vehicle can be attributed to the hydraulic disc brakes on the front axle. The other concept vehicles are equipped with drum brakes. At maximum delay, the wheels on the rear axle can lock. The locking of the rear wheels has little effect on driving behavior and can be assessed as uncritical. However locking front wheels, due to the resulting lack of steering ability, present a higher risk. In the test with the QuadRad, locking of the front wheels could not be achieved by intentionally over-braking the front axle.

For the QuadRad full brake application of the rear-wheel break at 25 km/h resulted in an average braking distance of 6.56 m (Table 5). In this case, the

**Table 2** Weight distribution

| | QuadRad | | City Shopping | | Babboe Big | | Babboe City | |
|---|---|---|---|---|---|---|---|---|
| Weight in kg | 60 | | 32.5 | | 61 | | 45.5 | |
| | VA | HA | VA | HA | VA | HA | VA | HA |
| Axle weight in kg | 24 | 36 | 9.5 | 23 | 48 | 13 | 22 | 23.5 |

**Table 3** Turning clearance circle

| | QuadRad | City Shopping | Babboe Big | Babboe City |
|---|---|---|---|---|
| Turing clearance circle in m | 4.35 | 2.92 | 6.85 | 5.88 |

**Table 4** Full brake application 25 km/h; both brakes

| | QuadRad | | | | City Shopping | | | |
|---|---|---|---|---|---|---|---|---|
| V. | $v_m$ (km/h) | $s_m$ (m) | $s_{kor}$ (m) | Acceptable breaking distance | $v_m$ (km/h) | $s_m$ (m) | skor (m) | Acceptable breaking distance |
| 1 | 25.5 | 3.2 | 3.08 | ✓ | 24.8 | 3.4 | 3.46 | ✓ |
| 2 | 25 | 2.6 | 2.60 | ✓ | 25.2 | 3.35 | 3.30 | ✓ |
| 3 | 25.2 | 2.7 | 2.66 | ✓ | 25 | 2.9 | 2.90 | ✓ |
| | Babboe Big | | | | Babboe City | | | |
| V. | $v_m$ (km/h) | $s_m$ (m) | $s_{kor}$ (m) | Acceptable breaking distance | $v_m$ (km/h) | $s_m$ (m) | skor (m) | Acceptable breaking distance |
| 1 | 24.5 | 4 | 4.16 | ☒ | 25 | 4.9 | 4.90 | ☒ |
| 2 | 25 | 4.8 | 4.80 | ☒ | 24.8 | 4.9 | 4.98 | ☒ |
| 3 | 25.3 | 5.9 | 5.76 | ☒ | 25.3 | 4.9 | 4.78 | ☒ |

**Table 5** Full brake application 25 km/h; rear brake

| | QuadRad | | | | City Shopping | | | |
|---|---|---|---|---|---|---|---|---|
| V. | $v_m$ (km/h) | $s_m$ (m) | $s_{kor}$ (m) | Acceptable breaking distance | $v_m$ (km/h) | $s_m$ (m) | $s_{kor}$ (m) | Acceptable breaking distance |
| 1 | 25.3 | 6.7 | 6.54 | ✓ | 24.8 | 7.15 | 7.27 | ☒ |
| 2 | 25.1 | 6.6 | 6.55 | ✓ | 25 | 7.6 | 7.60 | ☒ |
| 3 | 25 | 6.6 | 6.60 | ✓ | 24.9 | 7.3 | 7.36 | ☒ |
| | Babboe Big | | | | Babboe City | | | |
| V. | $v_m$ (km/h) | $s_m$ (m) | $s_{kor}$ (m) | Acceptable breaking distance | $v_m$ (km/h) | $s_m$ (m) | $s_{kor}$ (m) | Acceptable breaking distance |
| 1 | 24.7 | 7.3 | 7.48 | ☒ | – | | | ☒ |
| 2 | 25.2 | 7.9 | 7.78 | ☒ | | | | ☒ |
| 3 | 24.8 | 7.4 | 7.52 | ☒ | | | | ☒ |

minimum required braking distance of 7 m is not a problem. Blocking of the rear wheels could not be prevented for this test set up. The wheels usually lock right at the beginning of full brake application up to a complete standstill. The QuadRad remains, despite blocked rear wheels, in its track and can be easily controlled. In contrast it was not possible to control the other concept vehicles in this situation. In addition, the permitted braking distance could not be observed. The braking distance of Babboe City was over 10 m, the experiment was stopped because the vehicle was uncontrollable.

**Table 6** Steering input

| | QuadRad | | | | | City Shopping | | | |
|---|---|---|---|---|---|---|---|---|---|
| V. | L/R | $v_m$ (km/h) | $A_{min}$ (m) | $A_{min\_korr}$ (m) | Tilting | $v_m$ (km/h) | $A_{min}$ (m) | $A_{min\_korr}$ (m) | Tilting |
| 1 | L | 10.2 | 1.3 | 1.25 | No | 10 | 1.6 | 1.60 | No |
| 2 | L | 9.7 | 1.1 | 1.17 | Delay | 11 | 1.6 | 1.32 | No |
| 3 | R | 9.9 | 1.15 | 1.17 | No | 10 | 1.6 | 1.60 | Yes |
| 4 | R | 10.5 | 1.25 | 1.13 | Delay | 11 | 1.9 | 1.57 | Yes |

| | Babboe Big | | | | |
|---|---|---|---|---|---|
| V. | L/R | $v_m$ (km/h) | $A_{min}$ (m) | $A_{min\_korr}$ (m) | Tilting |
| 1 | L | 10 | 2.4 | 2.40 | No |
| 2 | L | 10 | 2.5 | 2.50 | No |
| 3 | R | 12 | 2.8 | 1.94 | Yes |
| 4 | R | 11 | 2.4 | 1.98 | No |

With a load of 17 kg, there were no major variations in braking distance. The concept vehicles are all designed for a payload from 22 kg (City Shopping) for a maximum of 180 kg (QuadRad).

The steering input test was not carried out with the Babboe City because this is a single-track vehicle. In addition, the behavior of the multitrack bicycles can be assessed in extreme situations. Sudden steering could cause a risk of tilting. The experiment was carried out with three concept vehicles at a speed of 10 km/h (Table 6).

The vehicles were steered twice to the right and also twice to the left. The cargo bikes partially lost contact with the ground and began to tilt. It should be noted that with the QuadRad the minimum distance could be achieved, although the turning circle of City Shopping bike is significantly smaller. Compared to the QuadRad, the distance measured for Babboe Big is nearly twice as large.

With the QuadRad, the test could even be performed at 15 km/h. On average a distance of 1.90 m was achieved. For safety reasons, the test of the other concept vehicles could only be carried out at 10 km/h.

**Table 7** Double lane change

| | | QuadRad | City Shopping | Babboe Big | Babboe City |
|---|---|---|---|---|---|
| V. | $v_m$ (km/h) | Course passed | Course passed | Course passed | Course passed |
| 1 | 10 | Yes | Yes | Yes | Yes |
| 2 | 15 | Yes | Take off | Take off | Yes |
| 3 | 20 | Yes | Take off | Take off | Yes |
| 4 | 25 | Yes | – | – | |

Double lane changing was run with the QuadRad error-free up to a speed of 25 km/h (Table 7). The QuadRad responds directly to steering movements and a relatively tight turning radius is possible. The successful completion of the course is quite simple with the single track cargo bike.

The bicycle's limits are reached at a top speed of 20 km/h. For safety reasons, the test was not performed at 25 km/h. With City Shopping and Babboe Big, tires already lost contact at 15 km/h.

The concept vehicles (including rider) have a relatively high center of gravity, which is why the maximum possible lateral acceleration in most cases is limited by the stability limit and not by the loss of adhesion of the tires.

With the Babboe Big, a lateral acceleration of 2.14 m/s$^2$ could be achieved at a speed of 11 km/h (Fig. 10). The rider was able to drive 2 km/h faster with the City Shopping bike, which is why a maximum lateral acceleration of 3.02 m/s$^2$ could be achieved (Fig. 11).

During steady-state circular testing with the QuadRad, a speed of 17.67 km/h could be reached. This is more than 6 km/h faster than the Babboe Big, which resulted in an average lateral acceleration of 4.5 m/s$^2$, which corresponds to 0.45 g (Fig. 12).

Both slaloms could be carried out with all four cargo bicycles. An exact and quick run-through of the course is possible with the QuadRad. Load changes can be completed quickly and curves can be passed through tightly. The City Shopping bike is more difficult to handle at 15 km/h as tires lost contact with the ground. After a period of familiarization, the Babboe City can be ridden without any problems. But the rider has to shift his weight greatly, which poses no problems with a single track bicycle. Completing a slalom with Babboe Big is very difficult, irrespective of speed.

**Fig. 10** Lateral acceleration—Babboe Big

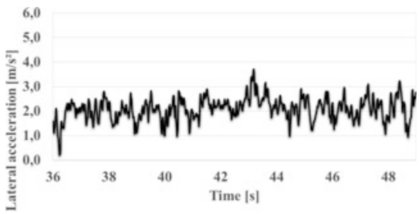
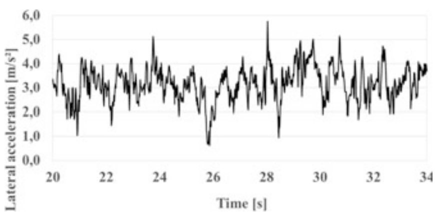



**Fig. 11** Lateral acceleration – City Shopping



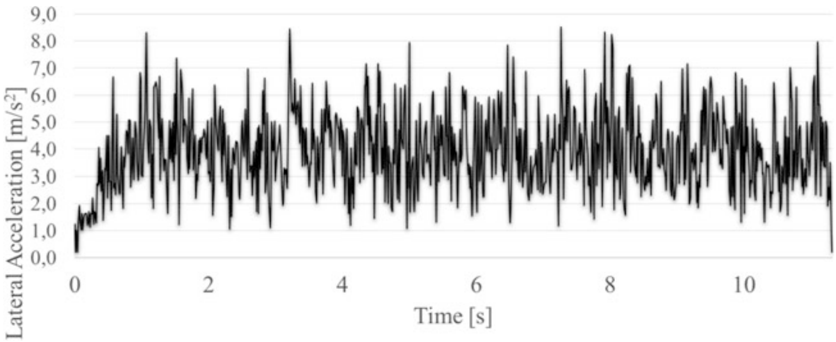



**Fig. 12** Lateral acceleration—QuadRad

# 4 Discussion

The results of this paper show that it is possible to test vehicle dynamics for multitrack bicycles. The tests were carried out on asphalt, with a bicycle the riders also use on forest roads, for instance. In order to analyze the outcomes, the tests can also be carried out on different road surfaces. The concept vehicle QuadRad was the basis for the experimental setup. The experimental setup was chosen and adapted according to the track gauge and wheel base of the QuadRad. Some results show, that it was difficult to reach the aims with the other concept vehicles. On the one hand, an adaption of some values, for instance the maximum allowable stopping distance, is possible, but on the other hand the concept vehicle QuadRad is a lead that the values are realistic and can be reached. Examining the results of the steering input, it is striking that the measured distances vary greatly. The test should be repeated with a given maximum distance, as it would then be possible to compare different speeds. Actually, the opposite is true—the speed is given and the distances are measured. Some tests, for instance full application braking, double lane change and slalom, should be performed with a payload. However, each concept vehicle has a maximum payload. In addition to that the suitability for daily use has to be analyzed for every concept vehicle. For the subjective evaluation, a study with about 30 test person was performed. They were asked to fill out questionnaires. The results of this study provided, among other things, knowledge of the driving experience, comfort, suitability for daily use and the rider's perception of safety with a concept vehicle. In combination with the results of the vehicle dynamic testing, it is possible to assess a vehicle with regard to the aforementioned characteristics.

## 5 Conclusion

So-called open and closed-loop maneuvers enable the comparison of different concept vehicles by measured variables. This is possible because the rider theoretically has no influence. In practice however, driving behavior is affected by posture when testing multitrack concept bicycles (as opposed to the car). This complicates a purely objective assessment, which results in inaccurate measurements. It is not possible to maintain the same rigid seat position throughout an entire test. However, the limitations of a multitrack bicycle can be determined by the vehicle dynamics tests mentioned above. These tests enable the comparability of different multitrack bicycles. In addition, a field test with potential customers has to be carried out over a longer period concurrently with the driving dynamic tests to get a complete picture of a new concept vehicle, In conclusion, a standardized testing procedure for multitrack bicycles is meaningful to enable a comparison and to ensure the safety of these concept vehicles. Moreover, testing is an indispensable part of the product development process.

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# Ergonomic Challenges in Designing Personal Cooling Equipment for Ultra-Deep Mining

**Valérie Tuyêt Mai Ngô, Sylvie Nadeau, Justine Mackowiak and Stéphane Hallé**

**Abstract** In ultra-deep mining, given the difficulties of the environmental conditions of heat and humidity and technical difficulties of ventilation and refrigeration miners must face, the idea of personal cooling equipment is becoming an interesting avenue. To the best of our knowledge, no such equipment is currently available on the market. To design this type of equipment, specific requirements must be met to ensure a miner's safety and productivity. To define these requirements, the authors undertook a literature review on the topic of constraints and requirements miners are faced with in deep and ultra-deep mining conditions. The results show that scientific and grey literature is scarce. A field study will be necessary to complete our knowledge and understanding of working conditions in Canadian ultra-deep mines. A matrix of requirements can then be established to design appropriate personal cooling equipment for ultra-deep mining workers and eventually, other hot and humid work environments.

**Keywords** Ultra-deep mining · Personal cooling equipment · Work conditions · Ergonomic constraints and requirements · Miner

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## 1 Introduction

Easily accessible lodes of mineral are slowly becoming depleted, but the need for new minerals has not diminished. Mining companies are thus following the veins deeper into the rock as far as 2.5 km, a depth that is considered to be ultra-deep mining. While some countries like Sweden and Australia have not reached these depths, some South African gold mines have already reached depths beyond 3 km [1]. In Sweden, the world's largest iron mine, Kiruna, is at a depth of 2 km, while in Australia, Mount Isa's Glencore mine (copper) reaches 1.8 km [2]. In Canada, for instance in the province of Quebec, one gold mine currently operates at a depth of 3.1 km and is evaluating the possibility of increasing to a depth of 3.7 km (Mines Agnico Eagle Limited 2015).

One of the main challenges associated to greater depths is the increased and ever present levels of heat and humidity that can sometimes exceed 40 °C and 75 % respectively [3]. The resulting heat stress can affect a miner both physically and psychologically [4]. With the added difficulty of providing adequate cooling and ventilation, which can represent around 18 % of a mine's production costs [5], the idea of a personal cooling system could be an interesting alternative. After all, a mining company relies to a certain extent on its workforce to be productive as well as cost effective.

However, to be able to design this type of equipment, it is necessary to understand the current conditions miners deal with in their everyday work. This is why this literature review focuses on miners, the constraints and requirements they are faced with in deep mining and ultra-deep mining with an emphasis on Canadian workers. This review includes both the working conditions and environmental conditions.

## 2 Method

To make sure that the most recent data was consulted, a systematic search of the available literature was limited to 1995 and beyond, in both French and English and using the following keywords: "mining", "deep mining", "ultra-deep mining", "heat stress", "working conditions", "workload", "underground miner", "environment", "constraints", "acclimatization", "safety", "vibration" and "miner".

Scientific resources and grey literature were consulted: Interdisciplinary databases (Inspec/Compendex and Scopus); Canadian libraries (Nelligan, BiblioÉTS); Canadian websites: *Institut de recherche Robert-Sauvé en santé et en sécurité du travail (IRSST)*, the *Commission des normes, de l'équité, de la santé et la sécurité du travail (CNESST)*, Natural Resource Canada (NRC), the Mining Association of Canada (MAC), Canadian Mining Journal (CMJ) and the Association paritaire pour la santé et la sécurité du travail du secteur minier (ASPMines); websites from other countries: Chamber of mines of South Africa (CM, South Africa), the *Institut* *national de recherche et de sécurité* (INRS, France), and the Human Factors and Ergonomics Society of Australia Inc. (HFESA, Australia).

Metalliferous mine documentation was preferred to coal or other types of mines because Quebec's deepest mines are gold mines. If the literature found was an article from peer-reviewed journals or conferences, the abstract was read and if the description matched the focus of this review, the entire article was read. For books, the table of contents was perused for relevant information. Finally, the "snowball" technique was used on the initial documentation selection.

## 3 Results

### *3.1 Definitions*

*Contrainte* in French can be interpreted in our situation as both a constraint and a restraint. In his 1984 work, Sperandio defines constraint as the work requirements for a given workstation under given working conditions independently from the operators' characteristics [6]. *Strain* according to Sperandio is the consequences of the constraint on the operator. It can be either physiological or psychological. *Exigence* in French or requirement is "A need or expectation that is stated, generally implied or obligatory" [7].

### *3.2 Laws and Regulations in Quebec*

In Quebec, metalliferous mines are subjected to two laws. The Mining Act (chapter M-13.1) regulates prospecting, claims and other such information. The *Loi sur la santé et sécurité du travail (LSST)* covers health and safety aspects and includes the special regulation called *Règlement sur la santé et la sécurité du travail dans les mines (RSSM).*

**Protective Equipment**. The RSSM lists mandatory equipment that a miner must wear during his work [8]. This includes:

- A safety harness
- A hard hat with variable accessories (earmuffs, headlamp, radio)
- Safety shoes or boots equipped with a metatarsal protector
- A scaling bar (if the miner has tasks involving scaling)
- Respiratory protective equipment (if the miner operates an excavating machine)
- Safety glasses

According to the Mining Industry Human Resources Council (MIHRC) miners will also wear a coverall with reflective markings, hearing protection and gloves [9]. Kenny et al. [3] estimate that the overall weight of the coverall and the following

**Table 1** Approximate weight of protective equipment based on information found on DBI-Sala website and the MIHRC

| Equipment | Approximate weight |
|---|---|
| Safety harness | 3.0 kg |
| Safety belt | 3.0–8.0 kg |
| Hard hat and accessories | 0.5–1.5 kg |
| Safety shoes (or boots) | 2.0–4.5 kg |
| Scaling bar | 2.0–14 kg |
| Respiratory protective equipment | 0.017 (N95 mask) to 25 kg (self-contained breathing apparatus) |
| Safety glasses | N/A |
| Gloves | N/A |
| Coverall | N/A |

protective equipment: hard hat with earmuffs, mining light and battery pack, safety belt, protective eyewear, work gloves, and PVC protective safety boots, is 8.5 kg. The approximate weight of the most commonly used protective equipment can be found in Table 1.

**Mine Regulations**. It is important to mention that each particular underground mine has its own regulations. Alas, it is impossible to list them all as they differ by country and company.

### *3.3 Shift Length and Effective Work Time*

The shift length duration agreed by most authors is between 8 and 12 h [3, 9–12]. As heat rises, the miner can undergo heat stress, which can then lead to heat-related illness in which Donoghue includes heat stroke, heat exhaustion, heat cramps and miliaria rubra (a skin rash that can develop after abundant sweating) [13]. In Quebec, the *Règlement sur la santé et la sécurité du travail* sets limits concerning the work/rest periods when under thermal strain [14] using the Wet Bulb Globe Temperature method (WBGT). This means that miners, when exposed to higher levels of heat, will have an effective work time that is less than their work shift duration.

Another strategy implemented by workers is self-pacing, which is when workers adjust their work rate to minimize or avoid physiological strain [15]. Xiang et al. [16] state that self-pacing “has been found to reduce heat strain in construction and mining industries in Australia, Germany and the United Arab Emirates”. During their case study on physiological demands of miners, Kenny et al. speculated that the small difference in average core temperature between significantly different mining jobs might be due to self-pacing. While some authors encourage self-pacing [13, 17], others such as Xiang et al. and Brakes and Bates [12, 16] state that it might put the miner or productivity at risk.

## *3.4 Environmental Factors*

Many factors can jeopardize a miner's physical as well as psychological safety in a mine. Table 2 summarizes the environmental factors most prevalent in the literature, however for the sake of brevity not all literature was cited in the table. The factors most likely to cause difficulties with personal cooling equipment are temperature, vibrations, humidity and dust.

**Heat**. In his article, Wagner lists natural and artificial sources of heat. The first natural source is the *temperature of virgin rock* (i.e. undisturbed rock) or geothermal gradient, which increases with depth and will subsequently transfer itself by conduction or during transport. The second is *auto-compression* by which the temperature increases due to a conversion of energy. Wagner declares "the principle of conversion of potential energy into enthalpy applies to any fluid and as such is also of importance when water flows into a mine." A difference of 1000 m in vertical depth amounts to a rise of 9.66 °C for air and 2.34 °C for water. This is significant if water is used for cooling in the mine.

As to artificial sources, Wagner mentions the *thermal engines* (diesel, electrical and compressed air operated equipment) as well as *explosives* and *people* [18]. There are other sources of heat but they contribute only 3 % to the overall temperature. Figure 1 summarizes the heat source contribution by type.

**Heat Stress Indices, Standards and Limits**. Tripti et al. define heat stress as "a state of the body where it is unable to dissipate the extra heat from the body to the environment." This can be measured using heat stress indices of which 45 are listed in the article [4]. There has been debate over which type of heat stress indices are best suited to evaluate the heat strain of miners and justify the enacting of preventative measures. Quebec laws ascertain heat strain using the WBGT index which is also widely used and recognized worldwide given that ISO and the National Institute of Occupational Safety and Health endorse it [1, 14]. WBGT factors in dry bulb temperature, vapour pressure or relative humidity, mean radiant temperature

**Table 2** Environmental factors in the mines

| Source | Environmental factors which the miner faces |
|---|---|
| Maurya et al. [4] | Heat stress |
| MIHRC [9] | Unsafe ground or terrain, extreme temperatures, dust, humidity, vapors/fumes, noise, electrical hazards, sharp tools, working in heights, vibration, moving objects or vehicles, confined work site |
| Walton et al. [33] | Rock stress |
| You et al. [31] | High temperatures, pressure, humidity, noise, toxic and harmful gases |
| Beaupré [34] | Absence of light, exposure to silica and other contaminants, dust, abrupt temperature changes, contaminated air (from machines and dynamite explosions), high humidity, high volumes of sound, open holes, dust, noise, danger of wall or ceiling collapsing |

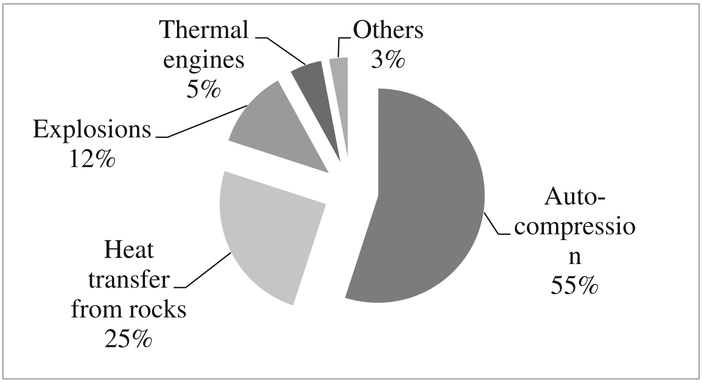


**Fig. 1** Proportion of heat sources by percentage at 3 km underground

and air velocity. However, Dessureault and Doucet stated that as of 1.7 km deep, the WBGT is no longer appropriate [19]. In his review Webber et al. state that different environmental conditions can result in the same WBGT and that the wet-bulb temperature is a good tool for routine monitoring. Webber et al. stress that while the wet-bulb index correlates decently with the physiological strain of workers, it evaluates only a single environmental component of heat stress. Dessureault and Doucet recommend the use of both the WBGT and ISO 7933 indices under certain conditions as follows: control of worker acclimatization, application of correlation factors for clothes worn, application of the more conservative measures, close medical follow-ups of the workers, training on thermal strain conditions and finally keeping water available at all times [20]. In his most recent work about the relevance and use of heat stress indices in Quebec, Dessureault mentions that the WBGT's valid range ends at around 32 °C and does not remain consistent when extrapolated while the ISO 7933 index has a larger range that ends at 39.8 °C and which tends to remain valid if extrapolated [21].

**Humidity**. In underground mining, water can come from two sources: groundwater and mine water [22]. Groundwater comes from rock reservoirs and can either be the same temperature as the surrounding rock or warmer. Mine water comes from drilling and other mining operations. For example, scaling involves dislodging unstable rocks from the walls with a metal bar. However before scaling can be done, walls and ceilings must be thoroughly washed down with water to remove dust and uncover any possible defects [23]. The evaporation of both these types of water releases more heat into the air and also raises the mine's humidity to levels that can be as high as 80 % to saturation [15, 19, 24]. High levels of humidity can make it difficult for workers to cool off since sweat cannot evaporate as easily, and sweating is one way the body cools itself [19].

**Barometric Pressure**. As mining companies mine to lower depths, the deeper the depth, the more the atmospheric pressure or barometric pressure increases. Franz and Schutte state that at a depth of 5 km, the difference in pressure would be an increase of 66 % or equivalent to 7 m deep in seawater, which is not enough to cause any effects to a healthy worker performing normal operations [25]. With temperatures that would rise to around 75 °C, mining that deep underground would make human presence highly unlikely. These conditions however are still far from today's reality since even the deepest gold mine currently in operation is at 3.64 km (Tautona mine, South Africa).

**Vibrations and Noise**. A field study was conducted by Marcotte et al. in 2011 in eight different underground mines in Quebec and on 28 types of mining equipment. The study focused on whole-body vibration exposure and noise. They found that ten of the 28 types of equipment exceeded the 8 h exposure limit for the vibration dose value (VDV) with pneumatic loaders (on rail and on tires) having the highest levels. As for noise, some noise levels for the same pneumatic loaders as well as drilling on aluminum scaffolding exceeded 110 dBA. Marcotte et al. noted that these types of equipment use compressed air to operate [26].

**Dust and Mud**. Most mine activities such as blasting and scaling generate a fair amount of dust. This dust is then removed, usually with water [23]. Although the issue of dust and particles in the air was raised, no information was found pertaining to dust and mud in deep and ultra-deep mining environments.

**Diesel and Other Gases**. The two types of gases usually mentioned in the literature are carbon monoxide and nitrogen oxides. Diesel particle matter is another pollutant that has been gaining attention since 2013 when the International Agency for Research on Cancer (IARC) of the World Health Organization (WHO) classified it as carcinogenic to humans [27, 28]. All of these gases result from operations such as drilling and explosions and vehicle circulation in the underground mines [29]. The extraction of minerals relies on diesel powered vehicles [30]. Methane which is a common pollutant and explosive gas in coal mines is not usually found in metalliferous mines since the gas results from the natural decomposition of biomass, which is less present in metalliferous bedrock. Most other references to air pollutants found in the literature are referred to as toxic or hazardous gases without a specific name [31].

## *3.5 Requirements*

**Men and Women**. Although mining is a line of work mostly occupied by males, miners are not exclusively male. Females are recruited, however in Sweden blue collar workers are 90–95 % men, numbers that Abrahamsson et al. [10] say are similar in other countries such as India and Australia. In a 2006 report published by the Women in Mining Canada organization, based on a census by Statistics Canada, women representation in Mining and Exploration in Canada is 14 %. Most of these women occupied jobs in culinary or administrative positions and only 4 % worked as underground/surface miners [32].

**Strength**. Mining activities will vary according to each miner's specialty. Movements such as lifting/lowering, carrying and pulling/pushing will necessitate a

**Table 3** Mining tasks strength and positional requirements

| Task | Lifting/lowering (kg) | Carrying (kg) | Pushing/pulling (kg of force) |
|---|---|---|---|
| Communicate | <0.5 to 8 | 1.5 to 2 | 4 to 22 |
| Prepare to go underground | <0.5 to 8 | 1.5 to 2 | 0 to 22 |
| Perform general inspection | 2 to 51 | 2 to 51 | Negl. to 10 |
| Perform general services | 1 to 51 | 1.5 to 47 | 1 to >50 |
| Scale loose rocks | <0.5 to 14 | 1 to 14 | 3 to 20+ |
| Install staging | 2 to 51 | 1.5 to 51 | Negl. to 50+ |
| Drill rock | 2 to 51 | 1.5 to 51 | 6 to 50+ |
| Install ground support | 2 to 51 | 1.5 to 51 | 3 to 50+ |
| Blast rock | <0.5 to 25 | 1.5 to 25 | 5 to 10+ |
| Muck | 2 to 51 | 2 to 51 | 5 to 20+ |
| Perform haulage duties | 2 to 25 | 2 to 25 | 5 to 20+ |

certain amount of strength [9]. Table 3 shows a summary of each mining task's strength and positional requirements according to the MIHRC report. Lifting/lowering includes floor to waist, waist to shoulder, floor to shoulder and above the shoulder. Carrying is unilateral and bilateral. Pushing and pulling includes vertical, unilateral and bilateral movement.

**Metabolic Rate**. Metabolic rates of miners may vary depending on the tasks. The maximum metabolic rate corresponds to the maximum speed at which heat can be dissipated from a body. Kenny et al. evaluated six different mining jobs with 36 participants in non-heat stress conditions to assess the physiological demands of their work. It was found that from between 3 and 16 % of the work shift duration, miners exceeded what ISO 7243 classifies as very heavy work (metabolic rate superior to 468 W). Their core temperature also rose above the 38 °C threshold recommended by the American Conference of Governmental Industrial Hygienists (ACGIH). Kenny et al. expressed concern on the fact that if miners exceeded recommended values in non-heat stress conditions, what would happen to these same miners in the actual heat stress conditions they would face at lower depths [3].

## 4 Discussion

**Ultra-deep Mining Literature**. Ultra-deep mining literature is scarce with less than 30 results in the Compendex/Inspec database and less than 100 in Scopus. However, the authors concede that mining tasks are similar at any level, thus expanding the research to underground mining and deep mining expanded their knowledge of the mining environment.

The information collected, such as the current weight of the protective equipment, the effective work time and the best heat stress indices will certainly assist in determining the maximum weight of personal protective equipment (PCE), the autonomy of this equipment and the best way to validate its effectiveness. The fact that there is no data in the literature on certain topics relevant to the design matrix of the PCE will be challenging. For example, data on dust and mud is inexistent yet important for certain aspects such as the upkeep of the equipment. To check the accumulation of dust and mud on the equipment, measurements will have to be taken in the short, mid and long term. Other topics while well documented will still pose a problem. For example, cooling the miner will almost certainly lead to condensation on the equipment or the miner. As for humidity, more energy is needed to remove moisture from air than to cool it down and as for vibrations, they will also have to be taken into account as they could damage small electronics embedded in the PCE.

The literature review brought to the authors' attention an known variable called self-pacing, which will have to be assessed and most likely regulated in the field tests, otherwise some participants wearing the protective cooling equipment might self-pace while others do not and this could affect test results.

To design personal cooling equipment that fits miners in Quebec, access to data related to their anthropometrics is necessary. Unfortunately, to the best of our knowledge, no such specific database exists as of the time of this article. Also, although miners are in majority males, personal cooling equipment design has to take into account female characteristics as well.

## 5 Conclusion

When researching for ultra-deep mining documentation, the authors were forced to recognize that there is very little literature available on the subject, with a combined total of only 130 results from the Scopus and Compendex/Inspec databases. This reveals to what extent ultra-deep mining is a recent trend and how little is known about the conditions workers face at those depths. No case studies on worker metabolic rate under thermal stress in ultra-deep mines were found, although there were many resources on heat stress, heat tolerance and acclimatization of workers based on traditional thermal stress indices, such as the WBGT. And, while there was no consensus on which thermal stress indices were most efficient in a mine, it would appear that the use of the WBGT index concurrently with ISO 7933 would be best to determine whether a worker is under physiological strain.

As scientific and grey literature is scarce, a field study would be necessary to complete our knowledge and understanding of working conditions in Canadian ultra-deep mines to establish the constraints and requirements for personal cooling equipment for ultra-deep mining workers.

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# Change the Mental Model, Change the Behavior: Using Interface Design to Promote Appropriate Energy Consuming Behavior in the Home

**Kirsten Revell and Neville Stanton**

**Abstract** This paper considers how designs of typical home heating systems fall short in the way they communicate their function to householders, and offers a 'mental models' approach to design as an alternative. Revell and Stanton (Appl Ergon 45:363–378, 2014, [13]) identified that inappropriate mental models of heating controls influenced users' behavior strategies to conserve energy. Domestic energy accounts for approximately 30 % of UK consumption, and 60 % of this is as a result of space heating (DECC 2013). Previous work by the authors' drives the focus of design changes at both the device and system level. Guidelines by Manketelow and Jones (Applying cognitive psychology to user-interface design. Chichester: Wiley, 83–117, 1987, [11]) and Norman (The Design of Everyday Things, Basic Books, New York, 2002, [8]) are used to understand how existing devices may unintentionally 'say the wrong thing' and improve functional communication in the redesign. Feedback from a pilot study using a simulator to demonstrate the resulting 'control panel style' of heating operation is also provided.

**Keywords** Mental models · Human-systems integration · Behavior change · Domestic energy · Space heating · Energy reduction · User centered design

## 1 Introduction

Home heating controls, like other devices in the domestic domain, suffer from the problem that users are given no formal training on operation, and instruction manuals are often not consulted, too difficult to understand, or missing [1, 2]. Domestic energy consumption accounts for approximately 30 % of UK

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consumption, and 60 % of this is as a result of space heating (DECC 2013). Home heating devices therefore indirectly control approximately 18 % of the UK's entire energy production, but are often misunderstood or operated incorrectly [1, 3, 4].

Sauer [5] described central heating as the most complex system in the domestic domain. When users try to interpret complex systems, they access their mental model of the system to guide their behavior [6]. Part of the complexity is due to the slow responding nature of the central heating system. Inherent in slow responding systems, is the difficulty to gauge cause and effect by observation alone [7]. In addition, the user is faced with multiple distributed controls that vary between households in their location, interface and functionality. Optimal comfort and consumption levels are dependent on the compatible adjustment of integrated controls presenting even the most knowledgeable, or well intentioned householder with a daunting task.

Over the last 30 years, the notion of mental models has been applied as a strategy to understand the reasons for inappropriate interaction. These range from research into consumer devices [8], computer interfaces [9, 10] and complex systems [6]. This paper uses design principles, recommended by Norman [8] and Manktelow and Jones [11] to create a 'mental model promoting interface'. It focuses on design solutions to evoke appropriate mental models in the user for individual heating control devices typically found in the home, as well as provide a system level design solution to promote a mental model of the relationship between these controls. Key devices were chosen, comprising the thermostat, programmer, and boost button. How the setting choices on these devices combine to enable boiler activation and radiator output is made explicit in the designs to promote a mental model of cause and effect in the user, to guide appropriate energy consuming behavior.

This paper describes concept developments based on a mental model promoting design specification [12]. A brief description of the development of a simulation to test the effectiveness of the redesign, as well as changes resulting from a pilot are provided. Limitations of the design, as well as further enhancements are explored and how the existing design meets recommendations for improving interaction with energy consuming devices in the home is discussed. It is proposed that designers consider the redesign of home heating controls at the system level to evoke functional mental models in the user.

## 2 Concept Development

The authors investigated standard home heating controls used in prior research studies [13, 14]. These studies indicated interface design contributed to inaccurate mental models of device function that influenced user behavior with heating controls. This section will first consider how traditional design of the Thermostat, Programmer, and Boost controls and for the system as a whole falls short. Next, suggested changes in the interface design, following design guideline developed by Revell and Stanton [12] with references to recommendations for evoking and triggering mental models by Norman [8] and Manktelow and Jones [11] will be presented. Example concepts of a control panel incorporating these redesigns are shown in Figs. 1 and 2.

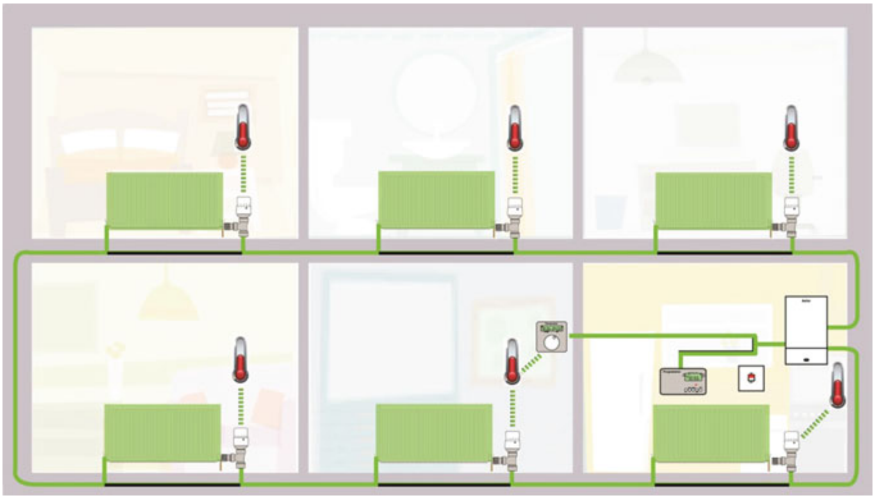

**Fig. 1** Redesign of interface to display distributed control devices with cause and effect links

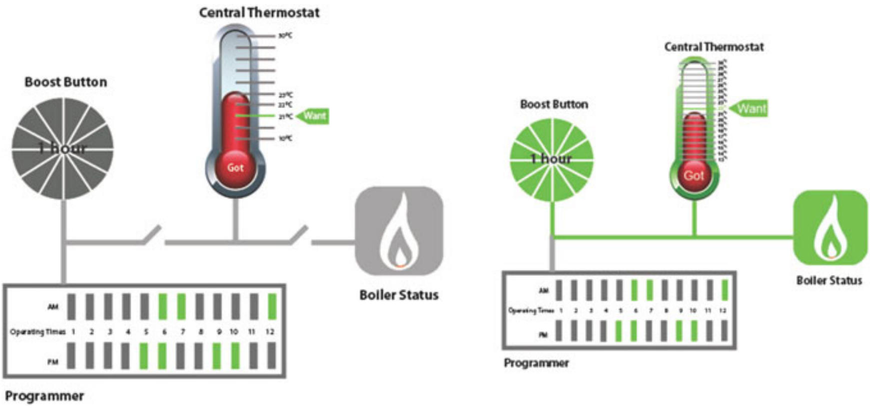


**Fig. 2** Control panel design to promote an appropriate system view of heating controls by emphasizing a link between set point choice with key controls and boiler status. Figure on the *right* shows boost button, central thermostat and boiler status highlighted in *green* when all active

## 2.1 The Problem with Traditional Heating Control Design

The authors considered the interface design of a traditional central heating thermostat (e.g. the Hortsmann—HRT4-ZW). Central thermostats only measure a temperature value from 'sample' point for the whole house. Thermostats are feedback devices, that turn the boiler on or off to achieve a set temperature. It shows current temperature sampled at the thermostat location (often labeled 'room'), and the target temperature value (usually labeled 'set'). Traditional thermostats have a control knob analogous to those found on a 'gas hob'. A gas hob control functions as a valve to increase or decrease temperature. According to Manktelow and Jones [11], users' familiarity with one style of control, can trigger a 'schema' that a device with a similar style control, works in the same way. Kempton [1] estimated up to 50 % of users in the USA, at the time of his research, erroneously held a 'valve' mental model of the thermostat, resulting in less appropriate operation.

Programmer devices allow the user to schedule time periods that the boiler can be active. Usability issues with home heating programmers are well documented [4]. Revell and Stanton [14] argue that the usability issues of typical programmer devices create 'metaknowledge' [15] in user mental models (UMMs) of the home heating system as a whole. This metaknowledge acts to dissuade users from including the programmer device in strategies to control heating, as they demand to much mental effort for operation. The authors considered a typical programmer (e.g. Horstmann CentaurPlus 17). As with most devices of this type, the difference between scheduled end times and continued comfort levels due to residual heat is not highlighted. This prevents thermodynamic lag times forming part of UMMs that could promote shorter programmer schedule times, so saving energy.

The 'Boost' button is also a common feature on traditional heating devices. The authors considered a boost button integral to a programmer device (similar to that found on the CentaurPlus 17). When pressed, 'BOOST' text is discretely shown on the LED for the duration of its one hour operation. Revell and Stanton [12, 14] identified that the function of the Boost button was not communicated clearly, nor was its conditional link to the thermostat for boiler operation. This led to the boost button being absent from UMMs or avoided in behaviour strategies, resulting in strategies at greater risk of energy waste [13, 14].

When a programmer, thermostat and boost control are used in combination, boiler activation is conditional on the thermostat device 'calling for heat' at the same time as a programmed schedule of boiler operation, or Boost activation. This conditional nature of operation is not communicated on traditional interfaces. The development of a function mental model at a system level by householders is therefore hindered. This was found to result in users assuming that programmed times equate to boiler on times [13].

Revell and Stanton [12] highlight how a typical system view of home heating has characteristics that impeded development of an appropriate UMM by householders. Presenting a range of different controls of varying prominence distributed around the house, risks some controls being overlooked [13], the hierarchy of controls being misunderstood [14] and metadata for effort involved in controlling or checking device status preventing appropriate actions with, and evaluation of, the heating system [12].

At the system level, a lack of clear visible connections between devices prevent interdependency of devices being emphasized and cause and effect rules being developed [12]. Home Heating controls are typically distributed around a home, with the central thermostat in the hall, Thermostatic Radiator Valves (TRVs) in each room, and programmer/boost and other controls in additional rooms (e.g. kitchen, hall). The householder can only be present in one room at a time, meaning they can only access devices for control and feedback, when present in the same room. Similarly they can only evaluate the progress with comfort levels for the room in which they are situated, limiting an overview of variations in comfort levels across the house. A conceptual representation of thermodynamic variations is hindered, through this 'tunnel vision' experience. Typical home heating systems, do not have a mechanism to communicate performance variations based on individual household thermodynamic data, This hinders thermodynamic concepts becoming part of UMMs, affecting expectations of performance.

### *2.2 Redesigning Controls to Evoke Appropriate Mental Models*

The authors redesigned the thermostat control to encourage the idea that existing temperature values fed back from a central temperature sample point are a key criteria for device function. Adopting guidelines by Manktelow and Jones [11], the design capitalizes on householders' likely familiarity with the form of a thermometer to trigger a schema relating to temperature measurement. Ambiguous language should be avoided, for the development of coherent mental models [11]. The Redesign of the thermostat is labeled a 'central' thermostat, and reference to 'room' is removed to avoid confusion with individual room thermostats. Norman [8] recommends that users should know what actions are possible and actions should match intentions. This was accommodated by changing the interaction from rotating a knob, to selection of the desired temperature using a 'Want' button.

Norman [8] recommends that the system state is readily perceivable and interpretable and is a match to user's intentions. The thermostat redesign indicates the current temperature measured by the central thermostat by increasing or decreasing the 'mercury' line within the thermometer analogy. In addition, the more meaningful label 'Got' (as opposed to 'Room') is used. By placing the 'Got' and 'Want' values on a single temperature scale, a concrete and immediate comparison of these values is apparent to the user. The functioning of the thermostat relies on this comparison of values (if the 'want' value is higher than the 'got' value, the thermostat 'calls for heat'). To meet the requirement that the effects of their actions should be visible to the user [8], the outline of the thermostat changes to green when calling for heat. The author's deliberately avoided using a flame icon used in traditional designs to prevent users being misled that an 'active' thermostat necessarily, equates to boiler activation (see Fig. 2).

The programmer was redesigned to overcome lack of use due to usability issues. Norman [8] suggest the structure of tasks can be simplified by minimizing the amount of planning necessary, and changing the nature of the task. The nature of the task was changed from navigating through a series of modes and options to input start and end times, to a simple 'point and click' task to select hour slots of operation. The new design makes visible the actions that are possible and how the action is to be done [8], and unlike traditional programmers it visibly displays the programmed schedule resulting from their actions by changing the timeslots to green. To indicate the system state, when a scheduled timeslot is 'active', the outline of the programmer is highlighted in green.

To aid its inclusion in heating control strategies, the authors increased the Boost button's prominence as a key control, and redesigned the interface to effectively communicate its one-hour operation. The analogy of a clock face is used to trigger users existing schema relating to time passing [11]. To avoid ambiguity of the activation period, '1 h' text is displayed, communicating what actions are possible [8]. Following Norman's [8] recommendations, the effects of user's actions are also made visible by highlighting remaining time in green, enabling easy evaluation of the system state.

In the redesign of the interface, 'tunnel vision' is removed by showing the comfort levels of all rooms in a single view (Fig. 1). This follows from Norman's [8] recommendation to ensure the system state is visible and readily interpretable. The intention of the design is that visibility of variations in comfort levels across the house will promote an understanding of lag times and thermodynamic variations in user's mental models of home heating. To make visible the outcomes of users' actions with TRVs following recommendations from Norman [8], the radiators are highlighted in green when water can flow, but not when the TRV acts to limit heat. This provides feedback of the effects of control adjustments on comfort (shown by variations in room colour) and device activation (links and devices are green when active) across the whole house, removing the obstacle of 'tunnel vision'.

Figures 1 and 2 combined represent the proposed 'control panel' interface redesign. Figure 2 shows how the conditional rule is emphasized to users, by grouping key controls by their relationship to boiler activation. An analogy of a 'switches in a circuit' is used to trigger a schema that guides the development of a functional user mental model [11]. Boiler activation is made visible (highlighted green) when the programmer or boost is active (closing left switch) and the thermostat is active (closing right switch). If one or both of these conditions are not met, one or both switches will be open and the boiler icon will remain inactive (grey).

To aid discoverability of controls, redesigning the interface as a 'control panel' enabled access to all controls and feedback from a single point. Manktelow and Jones [11] emphasizes that if appropriate dominance is not emphasized, it is unlikely UMMs will develop correct assumptions about dominance. The hierarchy of controls was established by placing the key controls visible on the main panel.

Less frequently used controls (e.g. TRV controls, boiler temperature, frost controls etc.) are accessed via a button from the main interface leading to 'advanced controls'. This follows Norman's [8] advocacy to deliberately made things difficult if there are undesirable consequences for operation.

## 3 Pilot of Redesign Using Home Heating Simulation

A simulation was created to enable the redesigned controls and interface to be compared in operation, to a more realistic interface (based on the typical controls and interface described). The simulation was developed to offer two versions of a home heating interface, with controls providing the same function 'behind the scenes' with a view to conduct empirical studies comparing user behavior in each condition. The realistic interface replicated the 'tunnel vision' experience by presenting a single room to users at a time, meaning feedback of the devices available, and the comfort levels achieved was only possible for the visible room. To reflect users' need to deliberately approach a device before operation, the representation of typical devices in the typical room, could only be accessed when the user clicked the correct room (e.g. 'entered the room') and the specific device (e.g. approached the device). A larger version of the device was then presented that allowed adjustment with the mouse. In contrast, the redesigned interface provided visual feedback of all rooms and access to key controls by default.

To avoid differences in opinion by users as to what temperature values constituted 'comfortable'—feedback was provided with descriptions ranging from very cold, cold, too cool, comfortable, too warm, hot, and very hot. For the purposes of the proposed study, the room temperature range for each of these descriptions was adjusted to ensure the user could not achieve comfortable temperatures without making adjustments to controls, to captures behavior differences resulting from each condition. A simple thermodynamic model was included whereby the rooms adjacent to outside walls lost heat at a higher rate than central rooms, and included changes to heat loss rates based on variations in external temperatures throughout the day.

Initial informal pilots were undertaken to identify and mitigate initial usability issues during interface development. Following this, a formal pilot for each condition was undertaken. This ran through the whole experimental procedure, and provided feedback about the experience from a participant's point of view. The pilot candidates were both PhD students in Engineering and the Environment in their mid 20 s. Relevant to this paper, the issues identified relating to the Redesigned control panel style interface comprised: (1) The rooms overview was too cluttered, making it difficult to know what to focus attention on; (2) The Boost label was misleading, (3) The TRV control purpose was not clear, and; (4) It was not evident the thermostat could be interacted with. To mitigate these issues, the rooms overview was decluttered by removing the thermometers and associated links to the radiator controls. Further, lines linking the programmer and thermostat to the boiler. The Boost control was renamed as 'override' to better communicate its function, and the active parts of the thermostat controls were emphasized.

## 4 Discussion

Home heating control, like other devices in the domestic domain, suffer from the difficulty that users are given no formal training on operation and instruction manuals may not be consulted, are too difficult to understand, or missing [1, 2]. Whilst the impetus for this research is to help reduce energy consumption due to space heating, the focus in this paper is considered to be the first step towards this goal. The aim of the research is to change users' mental models through the way in which heating controls are presented to householders. It is hypothesised that the design and controls will promote more compatible models than traditional interfaces.

The design decisions made were directed from the design specifications to improve mental models of home heating, provided in Revell and Stanton (In Press) and design recommendations to evoke mental models in general, by Norman [8] and Manktelow and Jones [11]. Some aspects of the designs that made sense 'on the drawing board' did not work in practice (e.g. providing a link between key control devices on the house display, as well as a feedback link from thermometer icons to TRVs). This highlights the benefit of piloting design concepts. Some design considerations were made to ensure the use of a simulation for an experiment to test differences in behavior resulting from altered UMM provided sufficient data. This included not only potentially narrower than necessary criteria for room temperature values labeled as 'comfortable', but also a deliberate decision to enable unhindered access to the thermostat and programmer controls. These specific controls are considered long-term controls requiring initial and considered setup [12]. For application in a genuine domestic setting, it is recommended that different modes of access to these controls, depending on whether the user is using trial and error to determine appropriate set points to meet their needs (full access), or if long-term set points had already been established, and the user intends only to make adjustments for atypical goals (restricted access).

The body of literature that focuses on problems with energy consuming devices in the home, also offer up a number of recommendations for improving users interactions with technology. It is put forward that a mental models approach to design at both the system and device levels is likely to address a number of these. For example: realtime feedback, in this design, relating to comfort levels and boiler on periods [16, 17]; Clear display of device status [5]; improved discoverability and intuitive design of controls [18]; understandable temperature scales, in this case for the TRV controls [19]; preference for auto-reset features, supported in this design by providing increased prominence of the boost button [16]; peripheral positioning of controls (in this case TRV and advanced controls) to reduce frequency of adjustment and application of information proximal to controls [16]. In addition, Pierce et al. [20] and Peffer et al. [4] validate the relevance of generic design recommendations by Norman [8] by advocating designers make use of affordances and constraints, visibility, feedback, natural mappings and consistency when ensuring householders effectively operating domestic energy consuming devices. These, together with other recommendations in the literature, have much to offer. However, designers need to ensure that seemingly separate devices that in practice, will be operated in conjunction with other devices, need to communicate their dependencies. That is to say, they are 'improved' with consideration of UMMs at a system level.

## 5 Conclusion

Householders' behavior with home heating controls has a significant impact on energy consumption. Traditional home heating devices are ineffective at communicating their function and operation at both a device and system level. Poor communication of device function results in inappropriate UMMs of the home heating system. Combined with poor usability, this has an impact on the energy consuming behavior strategies adopted by householders. Designers should take heed when redesigning home heating controls, and adopt an approach that considers the impact on UMMs at both a device and system level.

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# Research on the Modular Function Design of Intelligent Lighting Equipment Based on Different Environmental Requirements

**Junnan Ye, Jianxin Cheng, Le Xi and Wangqun Xiao**

**Abstract** In recent years, the government and people have raised an upsurge of constructing smart cities, hoping to create a better urban life and environment. Traditional street lamp can be swiftly converted into the terminal of important technology in the future construction of smart city—multifunctional intelligent lighting equipment. However, users also hold different functional demands towards intelligent lighting equipment. Shanghai will be taken as an example here in this paper. In the form of questionnaire survey and interview, the demands of multi-functional intelligent lighting equipment in different urban regions are analyzed and studied in function-bearing, scene application, aesthetic demand, intelligent application and energy-conservation control, etc. The findings of the study will provide robust evidence and reference to the research and development of intelligent light equipment-related technology, and play a decisive role in the realization of the future construction of smart cities.

**Keywords** Environmental requirements · Intelligent lighting · Modular function design · Smart city

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## 1 Introduction

Along with the gradual development of human society and continuous elevation of urban informatization application level, series of problems such as population expansion and congestion, resource shortage and waste, environment pollution and governance, traffic jam and dispersion, as well as public security hidden danger and remediation have come one after another. In an attempt to solve these problems, the fervor of building smart cities has risen around the globe along with the continuous development of high and new technologies like Internet, Internet of Things and cloud computing etc. Smart city is the concept of urban development as per science, which, by utilizing a new generation of information technology and on the basis of overall perception of information and Internet, realizes a seamless connection among the function systems of people, things and cities, makes intelligent response to various urban demands such as people's livelihood, environmental protection, public security, government services and commercial activities etc. via associating with linked intelligent self-sensing, self-adaption and self-optimization, and forms safe, convenient, efficient and green urban morphology equipped with sustainable endogenous power.

Construction of smart city involves all fields, classes and regions of the city, which will trigger the fundamental revolution of modern city's operation form, management mode, production mode and lifestyle [1]. So far, there have been about 1200 "smart city" projects throughout the world that are under characteristic development and implementation [2]. In combination with digital city in earlier stage, China has constructed and boosted the strategic deployment and content demand of new-type urbanization. In 2012, it started the pilot work of smart city. During 2012–2014, there had been around 300 cities piloted by the housing ministry.

By taking intelligent lighting project of Shanghai, China as an example and utilizing the modes of questionnaires and users' interviews, the topic has been analyzed and studied with regards to functional requirement of multi-functional intelligent lighting devices in various urban regions from many aspects such as function bearing, scenario application, aesthetic requirement, intelligent application and energy-saving control etc. to obtain users' and environmental requirement in a comprehensive manner, transform design requirement accurately and systematically into modularized functional elements by analyzing technological means through Kansei engineering, and eventually construct modularized function design model of intelligent lighting devices based on different environmental requirements in the city.

## 2 Research Background

In the aspect of smart city construction and exploration, Sam and Peter [3] has analyzed the important effect and significance of constructing smart city on future urban development in the overview of smart city construction, holding how to drive smartness is the primary challenge encountered by the main cities. Hans et al. [4] have carried out analysis on current smart city view, verified the services of future Internet in smart city under the condition of user driving innovation and open environment, and obtained the viewpoints of ability to realize resource sharing of future Internet public services under open-ended condition. Gregory and George [5] have analyzed the new ecological state of mind of smart city, and brought forward that urban growth, efficiency, productivity and competitiveness etc. have been relevant to smart city construction. Gerhard SCHMITT has explored and studied the future city of smart city. He believes that realization of urban sustainability and elasticity in future is the goal of smart city construction. Moreover, he has put forward the geometric model of future city in the qualitative and quantitative aspects on the basis of spatial dimension [6]. Edward and Mary [7] have discussed the definition of smartness growth and ecological city, development approach and 14 sustainable development principles, and analyzed the influence of smartness growth and ecological city on striving for more sustainable development patterns. So far, studies concerning smart city construction project have been carried out in the aspect of simple system of physical infrastructure, information infrastructure, social infrastructure and business infrastructure etc., which has rarely involved in the development and study of comprehensive systematic products of intelligence terminal.

Urban intelligent lighting system has been developed to some extent abroad. Many countries have formulated industrial standards specific to street lamps in the city. On the basis of centralized control, modern street lamp control strategy pays more attention to functions of scenario and behavior analysis such as self-sensing illumination perception function, automatic on-off and dimming function as per the time of sunrise and sunset, as well as analysis function of stream of traffic and people etc. Moreover, there are different monitoring strategies regarding busy streets, out-of-the-way streets and highways. On the one hand, the control of street lamps is more humanized; on the other hand, it saves energy more efficiently [8]. In comparison, although the intelligent lighting in our country has enjoyed a rapid development, the overall level of our country's intelligent lighting still lags behind relatively. The vast majority of cities have had no street lamp monitoring system. In addition, the flexibility of street lamp is also poor, which cannot realize intelligent resolutions as per the functional requirements of the surrounding environment.

Through investigation and study, it is found that as important components of the city, the street lamp in the city enjoys unique advantages of wide coverage range, good communication position, accurate geographical coordinates and complete supply lines etc. The network platform based on Internet of Things covering entirely the city has been swiftly set up through street lamps in the city. Meanwhile, on the basis that comprehensive utilization of light poles is one of the important carriers of changing urban appearance and elevating urban connotation, we can, via multi-directional social collaborative design, add new functions of photovoltaic power generation, LED illumination, micro-base station, urban video probe, multi-media advertisements, information distribution, intelligent interaction, handy service for the public, battery charging poles, bioidentification technology, weather monitoring and intelligent sensory control etc., which make traditional street lamps swiftly turned into important technology realizing terminal of future smart city construction-urban multi-functional lighting devices. Consequently, on the basis of energy saving, it can improve space occupation of different function carriers, fully cover urban physical space, construct smart city Internet of Things, and enhance smart city project construction of energy-saving illumination, intelligent traffic and intelligent security and protection etc.

# 3 Research Method

## 3.1 Investigation and Survey on Intelligent Functional Requirement of Future Urban Street Lamps

The research team has studied bibliographic retrieval via the intelligent function requirement of future urban street lamp and interviewed 39 experts from 18 enterprises of R&D, production and manufacturing related to intelligent lighting like Moma Industrial Design Group, CECIC Lattice Lighting Co., Ltd, Huawei Technologies Co., Ltd, Shanghai Linshi Science and Technology Development Co., Ltd, Jiangsu Xiandai Lighting Group Co., Ltd, Shanghai Seeyoo Electronic Technology Co., Ltd, Shanghai Electric Power Co., Ltd, and China Telecom Group Company etc. As per the interview records, intelligent functions associated with future urban street lamps have been summarized into three major modules: energy saving, safety and function. The energy-saving module can be conducted via intelligent control mode and energy supply mode such as photovoltaic power generation, LED illumination and intelligent sensing etc.; safety module is mostly the requirement of citizens on help seeking system, monitoring system and detecting system such as urban video probe, bioidentification technology, weather monitoring and emergency call for help etc.; function module is in the majority of handy service for the public such as micro-base station, multi-media advertisements, information distribution, intelligent interaction, handy service for the public and battery charging poles etc., as shown in Fig. 1.

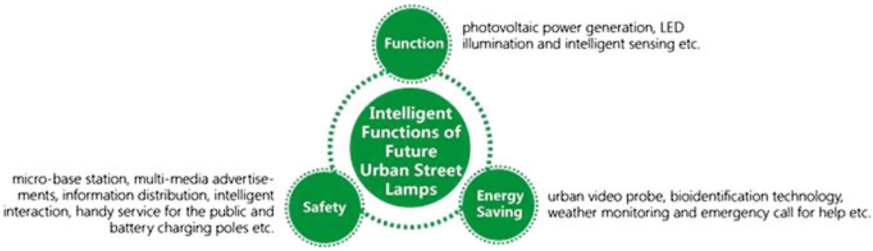


**Fig. 1** Intelligent functions of future urban street lamps

## 3.2 Investigation on the Status quo. of Urban Street Lamps—Taking Shanghai as an Example

As per literature survey and investigation, urban function regions can normally be divided into nine parts of administrative region, residence mixed region, pure residence region, scenic and green belt region, CBD, cultural and educational region, high-tech zone, industrial park, and suburban region.

The installation ways of urban street lamps include bracket type, tall type, straight-pole type, span-wire type and wall-mounted type etc.; the categories of urban street lamps can be classified as per the following concentrated ways:

(1) Classified as per height of street lamp: high-pole street lamp, medium-pole street lamp, road lamp, garden lamp, and lawn lamp etc.
(2) Classified as per texture of lamp post: hot galvanized street lamp, steel street lamp and stainless steel street lamp etc.
(3) Classified as per modeling: Chinese lamp, antique lamp, landscape lamp, one-armed street lamp and two-arm street lamp etc.
(4) Classified as per power supply mode: electric supply lamp, solar street lamp and wind-light complementary street lamp etc.
(5) Classified as per light source: sodium street lamp, LED street lamp, energy-saving street lamp, and new-type Somin xenon street lamp etc.

Taking Shanghai as an example, the research team has selected three typical locations in every region to carry out field visit and investigation in the way of sampling survey, specifically as shown in Table 1.

**Table 1** Sampling survey region of the status quo of Shanghai street lamp

| Urban region | Sampling survey region |
|---|---|
| Administrative region | Shanghai Municipality People's Government, Minhang District People's Government and Xuhui District People's Government |
| Residence mixed region | Shanghai Bay Palace, Xinhui Nanyuan, Shanghai Normal University New Residence |
| Pure residence region | Residence region near Minsheng Road, Shanghai, Villa area of Venice Garden in Shanghai, Shenmin Villa Area |
| Scenic and green belt region | Bund scenic spot, People's Park and Century Park |
| CBD | People's Square, Pedestrian Street at Nanjing East Road, and Shanghai International Financial Center |
| Cultural and educational region | Songjiang College Town, ECUST, DHU (Yanan Road Campus) |
| High-tech zone | Jinshan Science Park, Wujiaochang High-tech Industrial Park, Zhangjiang High-tech Industrial Development Zone |
| Industrial Park | Jinshan Industrial Park, Shanghai Chemical Industrial Park, and Shanghai Baoshan Industrial Park |
| Suburban region | Haiwan Town in Fengxian District, Nanjiangbang in Songjiang District, and Hangzhou Gulf Avenue in Jinshan District |

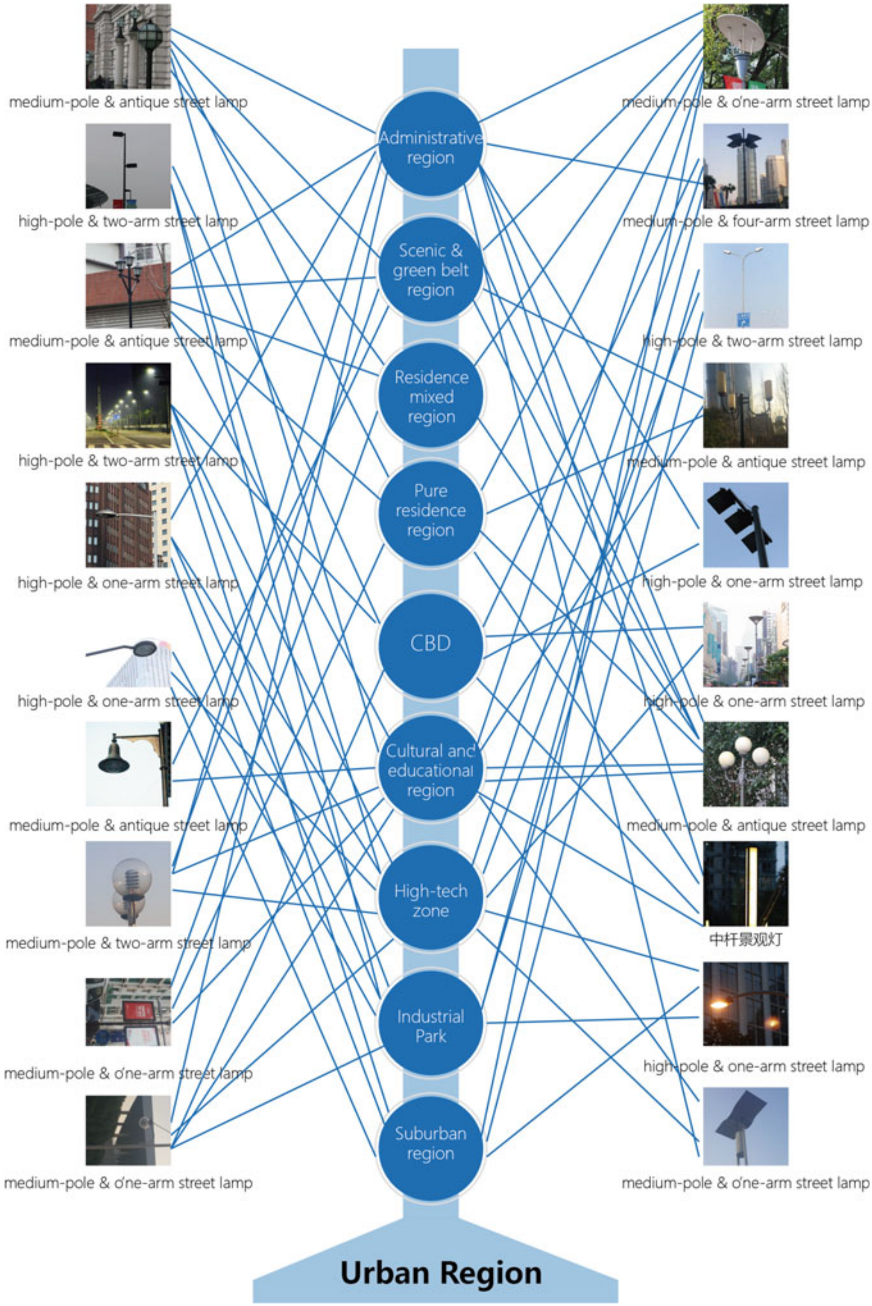


**Fig. 2** Investigated status quo of street lamps in Shanghai

In the way of field visit and investigation, we have carried out field visit and investigation into street lamp size, modeling, function, environment, texture and light source etc. of nine urban function regions and 27 sampling sites. Through survey and analysis of the status quo of street lamp in each region, we have summarized the status quo of street lamps in Shanghai, as shown in Fig. 2.

### *3.3 Investigation and Survey on Functional Requirement of Intelligent Illumination Devices Under Different Urban Environmental Requirements*

In combination with summarized intelligent function of future urban street lamps in earlier-stage study and survey results of street lamp's status quo under different environments in Shanghai, corresponding points have been sought between street lamps and different intelligent functions under different urban environments in the form of brainstorm. Moreover, questionnaires have been compiled. In the form of questionnaire, we have sought for the potential demand of users on urban intelligent illumination device function. Eventually, in different regions of Shanghai, altogether 246 questionnaires have been handed out; 232 have been taken back and 219 are valid.

## 4 Research Results

Through studying and analyzing survey questionnaires, it have been found that the biggest problems of current street lamps are single function, lack of sense of design in modeling, and lack of electricity saving design etc. Currently, urban citizens have had some knowledge on intelligent illumination, believing that warm-colored light source of street lamp (like faint yellow) makes people feel comfortable. The concern on design of intelligent illumination mainly concentrates on intelligent adjustment and energy saving, and manual control is the main control mode of street lamps currently. Functional and environment modeling requirements of intelligent illumination device users in various regions in the city are as shown in Table 2.

Through invitation of related experts and modes of brainstorm, intelligent function that can be combined with future urban street lamps have been summarized, as shown in Fig. 3.

**Table 2** Functional and environment modeling requirements of illumination devices under different urban environments

| Urban Region | Functional requirements | Environment modeling requirements |
|---|---|---|
| Administrative region | Work place requires the function of street lamps to be practical and prioritized without excessive decoration | Elegant appearance, conciseness, avoiding excessive decoration, greener, environmental protection and energy saving |
| Residence mixed region | Street lamp is required to meet the demand of illumination, energy saving and environmental protection, and attention should paid to renovating ageing street lamps | Characteristic morphological appearance design and function design specific to the module in this region with more local features |
| Pure residence region | Require more convenient services, meet the daily requirements of residents, and combine the convenient services with elegant appearance of illumination devices | Appearance can be correspondent to the surrounding environment, and the combination of convenient services and elegant appearance integrates with the surrounding environment |
| Scenic and green belt region | Provide sufficient illumination and meanwhile meet the aesthetic needs of pedestrians, beautify urban environment | Appearance can be integrated into the surrounding scenery, greener and more environmentally friendly |
| CBD | Meet diversified needs of pedestrians, and provide functions of charging, map and instruction etc. | Simple and modern, demonstration of urban landscape, and able to be harmoniously integrated into surrounding architecture |
| Cultural and educational region | Realize environment protection, energy saving and educational function; meanwhile, require convenient campus services such as recharge and notification etc. | Express profound cultural deposits of the campus with more novel and fashionable appearance, and conform to the demands of the young |
| High-tech Zone | Keep away from urban area, and remote roads need to be provided with map services | Fashionable technology, advocating green, environmental protection and energy saving, express regional characteristics |
| Industrial park | Add pollution detection function, and control the pollution conditions in industrial park. Specific to safety problems arisen from sparse population, emergency call for help is extremely necessary | Steady, practical, prioritized, require assistance in preventing and remedying pollution |
| Suburban region | Require street lamp intelligence to control illumination for energy saving and environmental protection, need one-key alarm function to remedy hidden danger caused by remote location | Practical function, modeling is required to be elegant, characteristic and of aesthetic values |

| Intelligent function / Urban Region | Energy-Saving | | | Safety | | | | Function | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Photovoltaic Power Generation | LED Illumination | Intelligent Sensing | Urban Video Probe | Bioidentification Technology | Weather Monitoring | Emergency Call for Help | Micro-base Station | Multi-media Advertisements | Information Distribution | Intelligent Interaction | Battery Charging Poles |
| Administrative region | ● | ■ | ● | ■ | ● | ● | ● | ■ | | ● | ● | ● |
| Residence mixed region | | ■ | ● | ■ | ● | ● | ● | ● | ● | ● | ● | ■ |
| Pure residence region | | ■ | ● | ■ | ● | ● | ● | ● | ● | ● | ● | ■ |
| Scenic& green belt region | ■ | ■ | ■ | ■ | ● | ● | ● | ● | ● | ● | ● | ● |
| CBD | | ■ | ● | ■ | ■ | ● | | ■ | ■ | ■ | ■ | |
| Cultural and educational region | ● | ■ | ● | ■ | ● | ● | ● | ■ | ● | ● | ● | ● |
| High-tech Zone | ● | ■ | ■ | ■ | ● | ● | ● | ● | ● | ● | ● | ● |
| Industrial park | ■ | ■ | ■ | ■ | ● | ● | ● | ● | ● | ● | ● | ● |
| Suburban region | ■ | ■ | ■ | ● | | ● | ● | ● | | | | |

■Installation ●Part of the installation

**Fig. 3** Modularized functional requirements of intelligent illumination devices under different urban environments

## 5 Conclusion and Prospect

The paper has conducted study on status quo of street lamps under different urban environments, intelligent function that can be combined with street lamps, users' intelligent functional requirements and modeling requirements on street lamps, as well as modularized functional requirements of intelligent illumination devices under different urban environments. The study will provide efficient reference and support for important implementation terminal of future smart city—urban intelligent illumination devices.

During the process of topic study, it is also found that R&D of urban intelligent lighting devices is no longer simple product design, which can be completed by a designer independently. It is in need of an innovative pattern and in dire need of an efficient operation mechanism. In order to realize intelligent functions of photovoltaic power generation, LED illumination, micro-base station, urban video probe, multi-media advertisements, information distribution, intelligent interaction, handy service for the public, battery charging poles, bioidentification technology etc. of urban multi-functional intelligent lighting devices, this needs to be completed via ultra-large enterprises with the technologies of Mobile Internet, big data, Internet of Things, cloud computing, intelligent sensing, remote sensing, satellite positioning, geographic information system and photovoltaic power generation etc. It also needs the support and guidance of related departments of government like traffic, information and propaganda.

The specific requirements on intelligent function of street lamps in different urban regions have certain generalities and differences. The paper also exists certain insufficiencies in the depth of needs study on intelligent illumination devices in a certain region such as extraction of modeling factor of intelligent illumination device under different urban environments, usability studies and modularization function etc. Along with the gradual penetration of study on smart city projects around the world, urban intelligent illumination devices will also be gradually realized and matured.

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# Using Cognitive and Physical Ergonomic Requirements to Promote Healthy Snacking Behavior: A Refrigerator Design Analysis

**Dara Gruber and Thomas Berry**

**Abstract** The science of Human Factors provides an important approach toward solving poor eating and drinking habits of US citizens. The focus of our three-prong investigation was to address the influences of snacking behavior. First, self-report interviews suggested that cognitive-behavioral factors such as cravings and food item availabilities were critical to poor snacking choices. Second, analysis of individuals' actual refrigerator contents showed snacking food and drink items were available form top to bottom shelves, but was more likely available as drinks (milk, juice, sodas, and alcohol) and as dairy products. Third, a review of anthropometric data revealed a decreased range of motion in obese participants in critical movements to the task of refrigerated snack selection. From this approach we concluded that current and common top-freezer style refrigerators fail to provide users with the organization and guidance needed to promote healthy snack selection.

**Keywords** Human factors · Ergonomics · Health and wellness · Decision-making

## 1 Introduction

In the United States, 34.9 % of people are overweight and obese, including adults, teenagers and children. Centers for Disease Control and Prevention (CDC) expect that many of these individuals are at risk for heart disease, stroke, type 2 diabetes and varying forms of cancer. CDC estimates annual medical cost associated with obesity

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to be well over $100 billion. Although, public health experts inform medical and media professionals how best to instruct and educate citizens and patients on how to lose weight, few are focused on understanding human factor solutions.

## 1.1 Literature

Snacking has the distinction of being superfluous and habitual, leading to unhealthy food consumption behaviors. Cross et al. [1] studied the snacking patterns of 1800 adults and children and discovered a high rate of snacking by subjects during the day. Researchers also found that the majority of snacking occurred at home and concluded that the majority of snacking is determined by what is available in cupboards or the refrigerator.

The next logical step is to understand how food is stored and made available to the consumer within their home environment. Food storage and its impact on healthy food choice was first supported by Coates et al. [2] during their examination of the relationship between body weight and food storage. The authors found a significantly greater number of overweight fathers in homes with higher calorie foods available in the first row of storage and concluded that humans have a tendency to consume food based on placement convenience. Wadden et al. [3] further supported the above findings by exploring the idea of a “toxic environment” in which highly palatable and calorically dense foods are very visible and easily available to the consumer.

Wansink et al. [4] conducted a study of candy consumption by manipulating both visual and proximal accessibility. The researches tested visibility by presenting the candy to participants in either a clear bowl or clouded, covered bowl. Proximity was a measure of manipulating the distance of the bowl from the consumer. Results showed that both proximity and visibility can increase food consumption in adults. Similarly, findings from Uetrecht et al. [5] suggest that placing vegetables and fruit in a visible area on refrigerator shelves increases accessibility and actual consumption.

Many of the authors cited above note visibility as a mediating factor to food selection. Visual attention and food selection have been further linked by Krajbich et al. [6] who revealed a bias towards selecting the first item seen. They found that items visually fixated on for longer periods of time are more likely to be chosen.

The reviewed studies focus on factors such as availability, proximity, and visibility, but fail to mention motivation. Experiencing hunger between meals is thought to be a primary motivator for snacking. Hunger is a powerful high-arousal drive state, which possesses both physiological and affective properties and has been shown to alter cognition. Read and Leeuwen [7] tested hunger induced selection proving that hungry participants choose more unhealthy snacks for immediate consumption than satiated participants. This study speaks volumes to the fulfillment of a need (hunger), in decision-making and snack selection. However, food item selection is more than just a matter of visual attention. Olfactory perception may come into play, as well as physical motion limitations (ergonomics) such as bending and reaching.

Research proves that snacking behavior has a significant impact on consumers' daily food intake. Whether or not healthy snacks are selected is influenced by a number of cognitive and ergonomic factors. For the scope of this paper, we will focus on the epicenter for fresh food storage: the refrigerator.

Refrigerators come in many shapes and sizes; the four most common being side-by-side, French door, bottom freezer, and top freezer. Market research indicates that of the four different refrigerator styles, the top freezer models are least expensive and therefore most common in management owned residences and lower income housing. The average size refrigerator unit in US homes is about 21 cu ft., which yields just under 15 cu ft. of refrigerator storage. From this point forward, we will use the 21 cu ft. top freezer style refrigerator as a reference for all food storage, ergonomic, and cognitive analysis.

## 1.2 Theory

Our objective is to better understand the task of refrigerated snack selection; therefore, we must define the task at hand. Figure 1 is a subtask map of refrigerated snack selection using the aforementioned literature as a general guide. In the model, hunger serves as the main motivator for snack consumption. If the user is able to

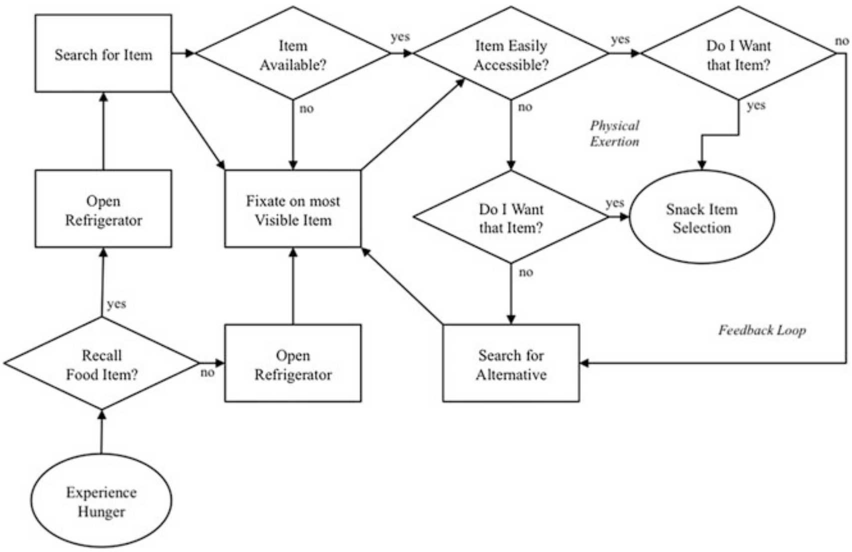


**Fig. 1** This subtask map breaks down the user's decision-making process to reflect physical and cognitive factors

recall a specific item in the refrigerator (relating to known availability), the user would then proceed to the appliance, open it, and immediately search for the recalled item in its thought location. From that point the user will do one of the following, (a) find the item, (b) consider it unavailable, or (c) get distracted by a more visible item.

If the user is unable to recall specific food items, fixation on the most visible item is the point at which those two paths converge. The user must then judge the item's accessibility. The extent that the user wants the item will determine how much time and physical effort he or she is willing to invest in obtaining it. If the item is unavailable, inaccessible, or undesirable, selection is delayed and the user is forced to search for an alternative. At that point, the feedback loop will be initiated and the user is likely to fixate on the most visible item. This loop will be repeated until an item is selected.

The purpose of our investigation is to understand how food placement within a common 21 cu ft. top freezer refrigerator influences snack selection. We take a three-pronged approach to exploring the above research question. First, we identify cognitive and behavioral barriers and affordances when confronting a typical household refrigerator. Research in this phase includes qualitative discussions around ideal storage space and self-reported snacking behavior. Next, we discover how people are actually storing items in the refrigerator. Through a systematic photo coding process, we identify categories of foods and map the items to a gridded location based on vertical placement. Finally, physical user requirements to complete the task of refrigerated snack selection are analyzed for both obese and non-obese users according to anthropometrics. From this regimented three part process we aim to compare the actual food storage in 21 cu ft. top freezer refrigerators to anthropometric averages to better help predict unhealthy snack selection. We postulate that current common refrigerator designs do not promote healthy snack selection.

## 2 Cognitive and Perceptual Requirements

Literature dictates trends in cognitive and perceptual factors that affect the task of snack selection. The following section strives to loosely replicate findings from previous studies through qualitative means and attempt to identify other emerging variables.

### *2.1 Method*

To elicit information about snacking behavior and home snacking environments, five in–depth user interviews were conducted. Additionally, 15 impromptu field interviews were conducted and an online survey was distributed to an online community via social media resulting in 30 completed surveys. In total, 50 participants answered the same two questions: self-assessing the healthiness of their snacking habits, and rank-ordering six identified motivational factors of snack selection.

## 2.2 Findings

All subjects have, on at least one occasion, attempted to make healthier snack choices. However, subjects additionally reported a low success rate, as illustrated by the comment, "*I am always trying to make better choices but unfortunately, not very successfully.*" When asked to rate in–home snack choices on a 5–point rating scale (1 = Very unhealthy; 5 = Very healthy), respondents gave themselves a consistently neutral rating (3.26). Snacks considered to be healthy included fruits and vegetables, pretzels, cheese and baked snacks. Common problem foods were chocolate, salty foods, pastries, cookies and "*anything in a bag*."

There were many common barriers to healthy snack selection, including: items not being readily available and prepared, family bringing unhealthy items into the house, and cost indicated by a participant who commented that, "*healthy foods are usually more expensive and don't last as long*". Respondents ranked "cravings" as most influential in their in -home snack selection, followed by "item availability" as indicated in Table 1.

When subjects were asked what an ideal home environment would look like to support their healthy snacking behavior, a number of interesting strategies were proposed. However, there were clear themes that emerged from the responses across all data collection methods. Common suggestions included: (a) hide unhealthy snacks (or not purchase them) in the back of storage areas and make healthy snacks more visible, (b) make healthy snacks readily available, (c) create more room for organized healthy snack food storage, (d) keep snacks on hand that do not need preparation time (grab and go), and (e) make healthy foods more appealing.

**Requirements**. Requirements of visibility and perceived accessibility were validated by user interviews. Additionally, hunger as the main motivator for

**Table 1** This table shows the percentage of participants (n = 50) and how they ranked each barrier

| Barriers to healthy snack selection | 1 (%) | 2 (%) | 3 (%) | 4 (%) | 5 (%) | 6 (%) | Average rating |
|---|---|---|---|---|---|---|---|
| Caloric nature | 12.0 | 12.0 | 16.0 | 24.0 | 18.0 | 18.0 | 3.78 |
| Time | 22.0 | 16.0 | 10.0 | 22.0 | 18.0 | 12.0 | 3.34 |
| Cravings | 26.0 | 20.0 | 22.0 | 14.0 | 14.0 | 4.0 | 2.82 |
| Effort | 8.0 | 22.0 | 24.0 | 20.0 | 22.0 | 4.0 | 3.38 |
| Item availability | 24.0 | 20.0 | 22.0 | 14.0 | 14.0 | 6.0 | 2.92 |
| Expiration dates | 8.0 | 10.0 | 6.0 | 6.0 | 14.0 | 56.0 | 4.76 |

Average rating was used to determine importance to the task snacking was confirmed. In order to maximize selection efficiency, the requirement for motivation (hunger) is that hunger should not be so overwhelming that it inhibits both attentional resources available and time dedicated for search.

In terms of visibility, Wickens et al. [8] cite the importance of the foveal visual angle in visual perception and subsequent visual attention. Foveal vision is the area formed by the two degree angle surrounding the center of fixation. This area is high in visual acuity, low in sensitivity, and is the focal point in the user's useful field of vision. To calculate the area of foveal vision a simple trigonometric function is calculated: $70[\mathrm{Tan}\ (2)] = x$, where 70 represents the user's average distance from the refrigerator cabin in centimeters and is multiplied by the tangent of the foveal angle which is 2°. This results in a target diameter of about 2.4 cm, which is then multiplied by pi to get a circumference range of 7.5 cm. Therefore, for an item to be considered highly visible, it must lie within (or close to) the 7.5 cm circumference range which is the center of the top shelf in a top freezer style refrigerator.

## 3 Food and Drink Storage

Designers create spaces with particular uses in mind; refrigerators are no exception. The space on the door designed to comfortably hold a gallon of milk, the butter tray, and the crisper drawers made to keep fruits and vegetables fresh were all carefully constructed to enable food organization. The physical structures of these parts may be well designed as they are inherent and often used effectively by the user, but are they in convenient locations within the refrigerator? There is theory that the way and location of food placed (by design) in a refrigerator may actually steer food choices and eating habits (behavior). The goal in this section is to evaluate the refrigerator in terms of requirements needed for healthy food and identify trends in food storage by location.

Through systematic photo coding process, we identified the placement of food and drink items in 21 cu ft. top freezer refrigerators. Differential distribution of items across a refrigerator's top to lower shelves and item accessibility were tabulated. Our analysis aimed at noting possible items that might activate or trigger snacking.

### 3.1 Method

Participants were asked to take photos of their refrigerators for the purpose of documenting their personal refrigerator design (e.g., GE, Kenmore, and Samsung). To minimize participant bias and manipulation of refrigerator contents, participants were not aware that the contents of the refrigerators were being tabulated. Host institution's human subjects review board approved this deception procedure, which included informed consent and post-research debriefing.

Nineteen participants volunteered to take photos of their refrigerator's main cabin and door storage. For photos to be acceptable for analysis, the following criteria were used: (a) refrigerator was a top freezer variety with three shelves, and (b) items stored took up 50 % or greater of the possible immediate front shelf space (this was to exclude hardly used or relatively empty refrigerators).

Seven refrigerators met our criteria. Researchers then assessed each photo by documenting individual food or drink items and noting on each shelf the placement of these discrete items. Generally, items were then coded according to the United States Department of Agriculture's (USDA) nutrition guidelines; the MyPlate. MyPlate is divided into four Food categories: Grains, Vegetables, Fruit, and Protein. Additionally, as a side and fifth category, the recommendation includes a portion of Dairy. We added a grouping code to separate out Foods from Drinks. For Drinks, we identified five Drink categories: Milk, Juice, Soda, Water and Alcohol. Thus, Dairy was divided into a Food and Drink category, such that a yogurt cup was coded as a Dairy food item and milk was coded as a Drink item.

### *3.2 Findings*

Overall, across all seven refrigerators, 144 items were tabulated and coded. Because of camera angles and view perspective, identified items tended to be items near the front of the refrigerator's shelf. Thus, these 144 items represent a visual portion of the total number of items. Of the 144 items 37 items (25.7 %) could not be identified or coded reliably. Most of these items were food items stored in tubs and containers with no or obscured food labels. Thus, roughly 5 items per refrigerator could not be coded. Number of food items coded showed that: 27(33 %) were Dairy, 7(9 %) were Grains, 23(29 %) were Vegetables, 12(15 %) were Fruit, and 11(14 %) were Protein. Number of Drink items coded showed that: 6(22 %) were Milk, 9(33 %) were Juice, 4(15 %) were Soda, 3(11 %) were Water, and 5(19 %) were Alcohol. Food accounted for 80 items (74.7 %) and Drink totaled 27 items (25.3 %) (Tables 2 and 3).

These results suggest that refrigerators store, in large percentages, calorie rich Dairy foods and Milk drink items, and that these items are fairly distributed from top to bottom shelves. Much of the bottom shelf Dairy items included butter and yogurt items, while milk cartons and jugs shared the top shelf. Additionally, calorie rich Drink categories such as Juice and Alcohol appear more likely and prominent as top shelf placement, probably because of the large container sizes used to sell orange juice and wine. Both sodas and water containers seem more likely placed on the middle shelf.

Food items, in particular Vegetables, like Dairy seem well distributed from top to bottom shelves. Fruit items, although distributed, tend to be placed on lower shelves. Yet, a large portion (58 %) of Fruit items was identified as conveniently packaged and eaten fruit cups. The least likely Food items shown are Protein and Grain items, whereby meats tend to be placed on the top shelf and bread on the bottom shelf.

**Table 2** This table shows the percentages of food (Panel A) and drink (Panel B) items as a consequence of shelf placement

| Food items (N = 80) | | | | | |
|---|---|---|---|---|---|
| Panel A | Dairy | Grain | Vegetable | Fruit | Protein |
| Top shelf | 11.25 | 1.25 | 10.00 | 3.75 | 7.50 |
| Middle shelf | 6.25 | 1.25 | 10.00 | 6.25 | 6.25 |
| Bottom shelf | 16.25 | 6.25 | 8.75 | 5.00 | 0.00 |
| Total | 33.75 | 8.75 | 28.75 | 15.00 | 13.75 |
| Drink items (N = 27) | | | | | |
| Panel B | Milk | Juice | Soda | Water | Alcohol |
| Top shelf | 11.11 | 11.11 | 3.70 | 3.70 | 11.11 |
| Middle shelf | 3.70 | 14.81 | 7.41 | 7.41 | 0.00 |
| Bottom shelf | 7.41 | 7.41 | 3.70 | 0.00 | 7.41 |
| Total | 22.22 | 33.33 | 14.81 | 11.11 | 18.52 |

Thus, percentages are a result of the number of items on a shelf (e.g., #Dairy or #Juice items on Top Shelf) divided by total number of food or drink items (N = 80 and N = 27 respectively)

**Table 3** This table reveals the percentage of food (Panel A) and drink (Panel B) items as a percentage of total items on a specific shelf (Top, Middle and Bottom)

| Food Items | | | | | |
|---|---|---|---|---|---|
| Panel A | Dairy | Grain | Vegetable | Fruit | Protein |
| Top shelf (N = 27) | 33.33 | 3.70 | 29.63 | 11.11 | 22.22 |
| Middle shelf (N = 24) | 20.83 | 4.17 | 33.33 | 20.83 | 20.83 |
| Bottom shelf (N = 29) | 44.83 | 17.24 | 24.14 | 13.79 | 0.00 |
| Total (N = 80) | 33.75 | 8.75 | 28.75 | 15.00 | 13.75 |
| Drink Items | | | | | |
| Panel B | Milk | Juice | Soda | Water | Alcohol |
| Top shelf (N = 11) | 27.27 | 27.27 | 9.09 | 9.09 | 27.27 |
| Middle shelf (N = 9) | 11.11 | 44.44 | 22.22 | 22.22 | 0.00 |
| Bottom shelf (N = 7) | 28.57 | 28.57 | 14.29 | 0.00 | 28.57 |
| Total (N = 27) | 22.22 | 33.33 | 14.81 | 11.11 | 18.52 |

# 4 Physical Ergonomic Requirements

It is not uncommon for obese individuals to experience resistance to physical movement. In these cases, a higher expenditure of effort and energy is needed to accomplish tasks that require larger movements such as spinal and knee flexion. We use anthropometric data to objectively evaluate differences in motion for the obese population relative to refrigerator-based tasks.

**Table 4** This table shows how range of motion (ROM) is affected by obesity for the different parts of the body used in refrigerated food retrieval

| Physical attribute | Normal ROM | Obese ROM |
|---|---|---|
| Lumbar spine (extension) | 24° | 18.8°* |
| Lumbar spine (lateral flexion) | 35° | 28°* |
| Lumbar spine (unilateral flexion) | 58.1° | 53.7° |
| Thoracic segment | 147.5° | 131.8°* |
| Thoracolumbal spine | 96.2° | 72.3°* |
| Pelvic segment | 54.3° | 61.1° |
| Hip joint | 67.3° | 71.6° |
| Knee (flexion) | 128.9° | 113.8°* |
| Arm length (extended reach) | 83.5 cm | <83.5 cm |
| Shoulder (flexion/upward rotation) | 186° | 158.2° |
| Shoulder (extension) | 51.3° | 40.8°* |
| Shoulder (adduction) | 32.3° | 20.7°* |
| Shoulder (abduction) | 181.9° | 172.9° |
| elbow (flexion) | 131.8° | 129.3° |

*Denotes statistically significant differences

## 4.1 Method

ANSUR database and methodologies were used to compile statistics for 20 obese and non-obese participants [9, 10]. All detailed measurements were taken from a static standing position; a gait analysis was not included as walking is not needed for the scope of this refrigerated snack selection task.

## 4.2 Findings

The values in Table 4 reflect the mean of 20 average and 20 obese people [9, 10].

Both Gilleard and Smith [9] and Park et al. [10] found significant decreases in range of motion (ROM) in obese participants when compared to non-obese participants for seven critical motions to refrigerated snack selection Arguably the most important physical measurement is extended arm reach. Arm length is the static measurement from the back of the shoulder to the tip of the thumb, while extended reach adds on the forward rotation distance of the shoulder [11]. Item accessibility is directly related to extended arm reach as it provides for the majority of the user's ROM.

Other important physical attributes for navigating a refrigerator are spine and knee flexion. These movements are needed to retrieve items stored on shelves lower than the user's natural arm length and were found to have a significantly decreased ROM in obese participants.

**Requirements**. For physical accessibility to remain high and not deter users from an otherwise healthy snack selection, items require storage placement that limits ROM for extended reach, lumbar spine flexion, and knee flexion.

## 5 Discussion

With a large portion of the US population, at all ages, facing overweight and obesity health issues, solutions and innovations have become a public health imperative. Our paper has addressed this issue from a human factors approach using three methods: (a) interviews to discover motivations, (b) naturalistic observation to reveal food placement and accessibility, and (c) ergonomics to understand the physicality of selection. User interviews taught us the importance of understanding emotions and desires for alleviating hunger. Knowing the physiological basis allows designers to better create snacking scenarios (settings + behavior) whereby the *design* feeds gratification in healthy ways instead of poor ones. Understanding refrigerators in terms of user placements of foods and drinks allow designers and innovators to (re)consider the structure of a pre-eminent and iconographic *appliance*.

Obviously, refrigerators store items for food preparation and not necessarily for snacking. Yet, an assessment of food and drink items shows a different and qualified picture. In terms of snack triggers, the refrigerator is food and drink item dependent in that items are packaged in such a way as to require certain placement. In particular, both the size of milk, juice and alcohol containers (liters, gallons to half gallons), and convenience of yogurt and fruit cups are potentially stored in such a way as to afford access because of container size, or placed because packaging makes it easier to place the item. Smaller items like butter tubs, yogurt and fruit cups are placed on bottom shelves because they can be located there without much effort. Effort here is in both in the act of storing and retrieving the smaller packaged item. However, with this in mind, the packaging of actual fruit items (whole apples and oranges) or vegetables items (carrots and celery), foods that are ready-made are almost completely visually absent when the refrigerator door is opened.

The USDA's MyPlate guidelines suggest that portion sizes across the main food categories include: 30 % grains, 40 % vegetables, 10 % fruits and 20 % protein. Also, dairy is referred to as a smaller portion representing milk or a yogurt cup. In light of USDA recommendation, our assessment of seven refrigerators suggests that if individuals desire a meal, most refrigerators from top to bottom shelves have the elements for complying with the USDA recommendations. However, from a snack perspective, our assessment appears to show individuals will be more likely nudged toward calorie-rich dairy and drink items.

This claim is further supported by user-centered cognitive, perceptual, and physical requirements. From an approximate distance of 70 cm, the foveal-vision circumference of 7.5 cm would be in the center on the top third of the refrigerator cabin interior. Even with extending that visual circumference to include some of the periphery to more closely resemble useful field of vision, the bottom third of the unit is still not a focal visual priority.

From a physical standpoint, classes of movement can be used to determine an item's ease of accessibility. Full body movement including spinal and knee flexion are considered to be undesirable motions. When evaluating the main cabin of an average 21 cu ft. top freezer refrigerator, the bottom third of the unit (usually including both designated vegetable and crisper drawers) can be considered physically inaccessible requiring undesirable movements to reach the targeted items stored there. Obese users have decreased ROMs further limiting the reachable space thus rendering the bottom third of the refrigerator physically more demanding in terms of accessibility.

Finally, we conclude that current refrigerator shelf design is not conducive to strategic and healthy snack storage. With the majority of high caloric food and drink items being stored within the top third of the refrigerator cabin by spatial design, the likelihood of selection for those items increases based on tested principles of visible and physical accessibility.

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# Enhancing User Experience in Graphic Design: A Study in (Unusual) Interaction

**Marco Neves**

**Abstract** Conceiving graphic design projects is a daily work, although its technical processes are not always employed to enable a better user experience. Specially in the case of print produced objects that greatly depended on individual graphic expressions and on a technology that imposes a static outcome. Nevertheless, printed matter represents a significant amount of objects and products that face public attention on a regular basis. Meanwhile their users are changing. They are influenced by interactive features and the possibility of user participation prepared by various services. The user is understood as a central point in planning actions and without a deep insight of how will the user deal with interfaces, most technologies seem meaningless. This paper presents a practice led research on interaction and its transition to a graphic design project, conceived for print production, in order to promote a better user experience.

**Keywords** User experience · Graphic design · Interaction

## 1 Introduction

Printed matter still has, nowadays, a large influence on information, knowledge and communication. But it seems unchanged when facing a different context for its current use, dependent on an increased importance of users and their participation on systems and products that provide a user experience based on interaction. It is

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through every element and permitted action-reaction, that several artefacts have recently came to enable a better or worst user experience.

This balance between interaction and user experience not only seems worth more study, as it may benefit graphic design practice. The development of solutions in printed matter will gain from research on interaction, in particular, in the way it can be applied and described in graphic design projects.

We begin by discussing the concept of interaction, its relation to user experience and how it can be translated into a requirements list for graphic design. This enables an experiment in conceiving a model to be printed, where interactive features are applied. To test the implementation of those interactive solutions, we have considered the development of a generic case that can be used in several occasions, according to need. It means that no graphic layout is carried out in this phase, since it is not intended to dwell on the visual arrangement of any media. The purpose is to focus on possible behaviors for this object, rather than final outcomes; to explore the connection between an action and a reaction that presumes the presence of a user.

This experiment, with a detailed description of the process, can be understood as a research through practice, where the model becomes a structure for the later constitution of products.

The intention is not only to seek an emotive reaction to printed matter, but also to implement interaction as a regular procedure in graphic design, benefitting the material relations that printed matter has with their users. The designed model is presented as an interface, composed of a set of elements and actions that allow users to handle the object and access information, but also to get closer to the provided experience.

## 2 Interaction as the Basis for User Experience

Most design products and systems follow methodological frameworks in their process and they contemplate affordances. Printed matter, which represents a considerable amount of produced graphic design objects, although slightly having such characteristics, remain to explore and improve them. Mostly because the straightforward impression of it rely on conventional solutions, leaving to visual creation the responsibility to address them.

An interactive existence may enable printed matter to allow a better user experience. Interaction is already considered an enhancing factor for user experience in web design [1]. But the relation between interaction and graphic design is not properly studied and it implies a different approach to printed matter. The design output can no longer be based on the exclusive graphic assessment of the object in hand, but in accommodating features and structures for encounters. As we interact with the world it is understandable to expect a presence of such conditions in many aspects of our life. In graphic design it can be present with the purpose of establishing a relational design [2] through a programmed action-reaction, browsing configuration or a direct control over the interface, in a very similar way to what digital technologies use [3, 4, 5]. Allowing in this way an experience instead of producing materials for a one-way communication. At this stage, the designer's main concern should go beyond the object itself, extending to the design's effect and its implications on users.

## 3 Towards User Experience

Whatever technologies are employed; it is the designer along with produced objects that determine a user. A user can only exist after an object is made available. There is a relation of interdependence between user and object, in which the designer act as a mediator. So, just as objects exist because of their users, also users only make sense because they use objects [6]. We assume objects (or products and systems for that matter) are an expected result of a necessity or invention. This serves as guidance for the development of objects.

Designers operate a transformation in the user through a working process we call project. By controlling the outcome of a design project, they not only conceive the object itself, but the perception and the experience that the user will have of it. However, it is inherent to the design project, to always demonstrate a level of uncertainty when assessing the use of mass-produced objects, because the entire process is not in the designer's control [7]. No designer can be entirely certain about the real use given to the result of his work, even if being a designer or a consumer, might just be a matter of context [8]. This understanding of incomplete work by the designer makes necessary the involvement of the user in many circumstances.

Davis [9] states a shift from designing artefacts to experiences. As an example, designing a logo makes sense, not to be used separately but embedded in a larger visual identity project. This, in turn, is part of a broader branding concept, where various genres in various media and communications come together; which will make perfect sense at the time that the end user will relate to it, within the context of providing a service. This progression to consider people's experience reflects a different expectation in terms of design and specially, printed matter; that through the mapping of possible uses, we may obtain a better understanding of the relationship between an object and its user.

## 4 User Experience and Print Media

The connection between interaction and user experience can be stated in the position that the user can have. He can either be a consumer, a processor or a generator of interactivity [10]. But the experience varies upon the understanding of both designer and participant, since both might have different intentions. Admittedly interaction raises the problem of sometimes giving the user a false feel, of choice and control without restriction. It is actually a programmed, carefully

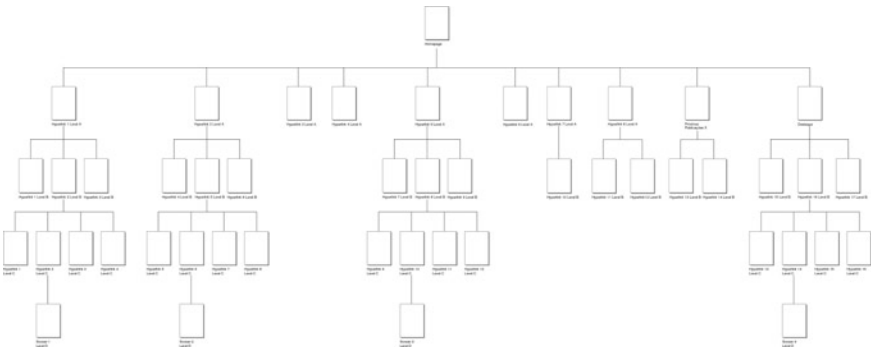


**Fig. 1** Browsing structure for a website


**Fig. 2** Sequence for regular access in a printed book

planned exchange of actions, that provides an experience related to user participation. So it is something not typically associated to printed matter.

This experience based on interaction is enhanced almost from the start with the ability to access various information, relatable to each other. Hypertext, by producing an association between text blocks, allows multiple readings and undoes, in part, the linear sequence, traditionally attributed to the printed book. With hypertext every reading will make sense. The reader is able to choose and to no longer be confronted with an imposed order. Its expanded use without restrictions of connection increases the levels of interaction offered in the digital medium when compared to what is made possible in print. For that purpose, Figs. 1 and 2 show the differences in planning a digital artefact, such as a website and a printed book.

Figure 1 presents a website basic structure for browsing. From the first screen, the index, we can choose several hyperlinks and each one of them offers different access through more hyperlinks. The entire number of connections for each screen (or webpage) is not made visible in order to better understand the relation between all parts of the website. Figure 2 presents the regular sequence used in a printed book, by showing the page number order and the reason for it, the book biding. Different lengths would require different numbers. To the sequence required in print, the website opposes a network access to information. These differences in planning will determine considerable differences in arranging elements and inevitably, in user experience. Being that a hyper textual and interactive experience may give way to personal creativity [11].

Although a certain use of interaction in printed matter could be recognized before the emergence of digital technologies [12, 13], the idea of user participation was really not included. In a way, to experience printed matter was not considered unless it involved informing people or taking more advantage of distribution to a larger number of users. It would not turn out to be a material relationship. Users would engage with this media by consuming products or reading spare messages. A print media that resulted from these concerns would not be designed to explore an interactive capacity, already present within the communication space.

Almost all know cases (books, magazines, newspapers, letterheads, posters, business cards or catalogues) are a traditional printed accomplishment, conceived with procedures that are based on a long track record of examples and that take for granted a certain production and distribution to people. They fulfil several functions and yet have so much in common. They all have a potential to increase the level of interaction, so any user can be a physical part of discovering information and increasing the emotional attachment to the product in hand. Of course print technology must rely on graphic elements to convey messages and to make them distinct. But their qualities and effects do not end here.

## 5 Experimental Project

A number of suggestions for producing interaction can be applied in print and improve user experience with it. To test the implementation of those interactive solutions in printed matter, we have considered the development of a generic model that can be used in several occasions, according to need.

The produced object may count as an experiment, a creative production that demonstrates concern with certain issues [14], the ones of interaction. This experiment can be understood as a research through practice [15], although it is not included in a specific method. Nevertheless, in some cases, the conception or construction of something assumes a large significance to prove an idea. In this case, that interaction may play a decisive role in printed matter to enhance user experience. The experiment applies some notions of interaction and aims to assess an assembled knowledge. The main concern was to design an object, easy and practical to handle, portable at the same time and as interactive as it can possibly be recognizable.

The model is designed as a fold out with two-sided print that allows two distinct, but equally combinable uses. It can be used and referred to as a small notebook, or even be manipulated while folding. The use as a notebook is reversible, meaning that there is symmetry in the structure of the object, when comparing front and backside. The lines dividing every zone and marking the folds, let users get to the last page of a printed side and immediately initiate the exact same use of the

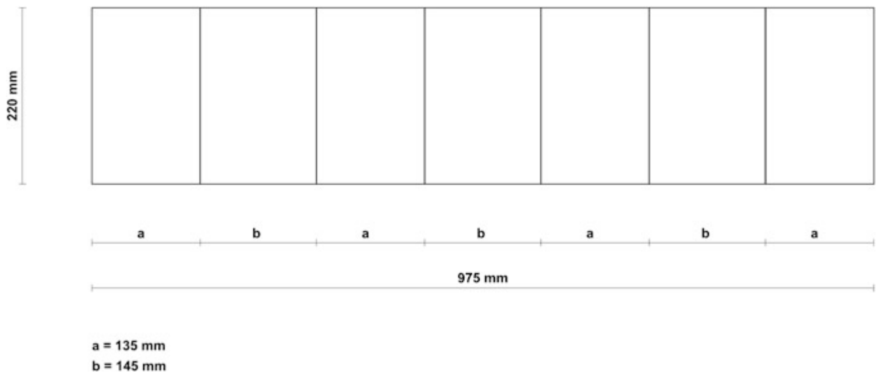


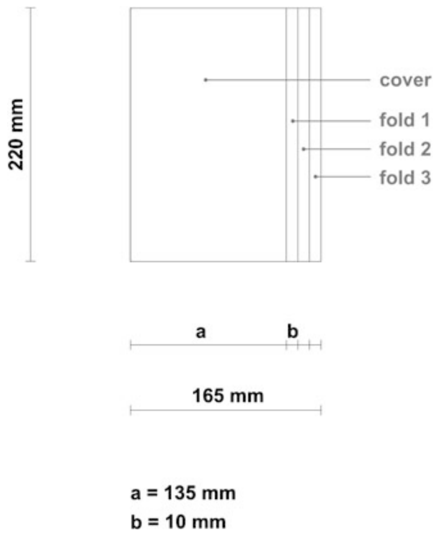

**Fig. 3** Folding system, dividing a print side in seven parts

reverse. To use it as a fold out, the user can hold the complete paper size, in its entire length and than fold it to form two different messages.

The object is based on a folding system as seen in Fig. 3, dividing the sheet of paper into seven parts, through folds between all of them. For this purpose, we present a print dimension of 220 × 975 mm, in order to take advantage of the length of the standard paper sheets of 700 × 1000 mm, used in offset printing system. In this way it is possible to produce three objects per paper sheet.

These seven parts were generated from two measurements always interspersed, which differ only 10 mm one from the other. This distance allows separating the folds, overlapping one after the other, except this precise 10 mm. The final presentation of the object after folding is shown in Fig. 4.

**Fig. 4** Folding closed and presented for notebook use



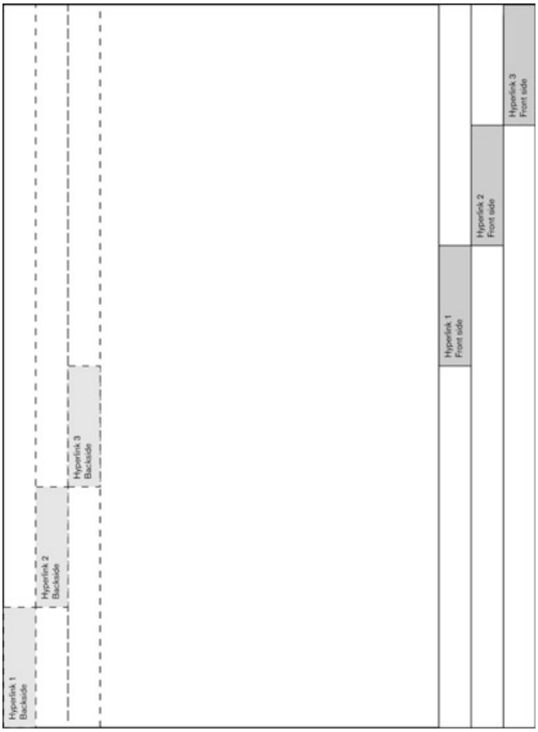



**Fig. 5** Folding closed with hyperlinks. Hyperlinks on the backside are presented in *dashed line*

The interaction notion of browsing is included precisely to present and select information. Several rectangles for headings are placed at the margins of the folds. One heading for each fold, placed in different heights. In this way, this print media becomes like a website, with the heading rectangles being similar to hyperlinks that enable browsing between the different information areas. Thus, when viewing each divided part, the user always knows what the next or the previous one is, replicating the known system for website browsing. When closed, the user faces a layout with all the accesses in the same way as when facing the computer screen. This can be seen in Fig. 5.

The user can choose and pick the fold (and consequent information) he wants. Much in the same way he "points and clicks", the user can access the information he pleases.

When opening the paper in its entire length, by placing the object in a certain position, the user can complete information. On each side, half of the layout space is divided into three different areas, interleaved, that are destined to place only one picture. The full picture is only perceived if the user holds the object and add a three dimensional perspective. Figures 6 and 7 present the areas for placing the picture and all the different places occupied with the several hyperlinks to maintain browsing possible.

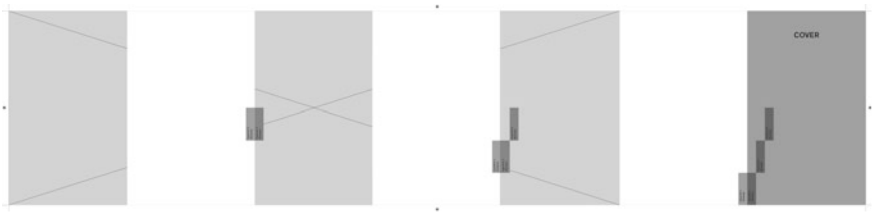



**Fig. 6** Model structure planning for the front side

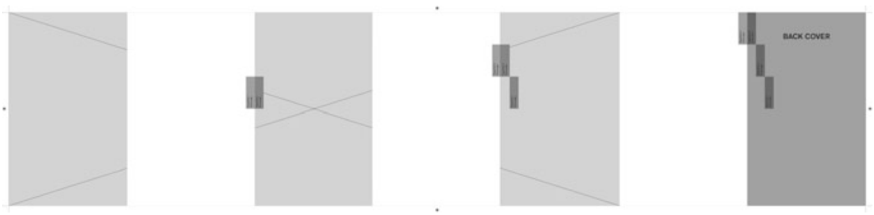



**Fig. 7** Model structure planning for the backside

Although this movement to complete information can be described in the same way as the "drag and drop" notion, because the user moves and reorganizes elements, this is a matter of visualization because we modify the way we can observe certain content.

All together, the model presents three ideas connected to interactive features. The folding structure enables two purposes, to consider the object, in the same way the user would face a graphic interface and to be handled in three dimensions. The group of hyperlinks function as affordances for the object that trigger a certain use.

# 6 Conclusion

Most products and systems have a capacity to involve their users in a relationship, for which they present at least one interactive feature. Printed matter has not been employing such strategy to improve the experience of it.

Nevertheless, the requirements for using graphic design objects have necessarily changed. Users now actively participate in the final form given to an object or system and can as well generate the content, which will form the object or system in itself. Even our daily experience with written language has gone from a linear and sequential perception, to the experience of choosing several paths. Therefore, printed matter should implement changes in their presentation and in the experience they provide to their users. There is a generation of people that will be very used to get involved and contribute to the making of products, services and systems, from the beginning. A digital environment that is gradually improving interaction performances brings up this generation. They will expect no less from any other production and those inadequate for such purpose may risk disappearing.

We have pointed a group of simple and daily interactive features. These function as principles for the enhancing of a user experience when considered in graphic design. They are instrumental in pursuing the research intention, but they are however still basic.

This group has served as knowledge to test in a print produced model, with its own properties. However, the same transposition can be made using different or new interaction notions, obtained from future studies. It can also be tested in very different models, originated from a careful calculation of users needs or specific situations.

We have generated an initial source for the development of print interactive-based solutions by testing interaction features in some detail. This relation has allowed envisioning a structured model that may benefit user experience, when adding an interpretation of interaction outside the digital and human-computer understanding. From this point it seems possible to further develop other media, in different dimensions, formats or materials.

There are some limitations in the process, in terms of applying interactive features and in meeting the procedures familiar with print production. Not all interaction can be applied, since it appears to be difficult to concentrate in just one media.

The model was prepared for small or medium quantity of contents. The process described here may benefit from testing in larger quantities of information and in more robust objects or products. Still, the designed model is presented almost as an interface, composed of a set of elements and actions that allow users to handle the object and access information, but also to get closer to the provided experience.

This unusual concern with interaction, justifiable due to user expectation, serves as a forward approach to a certain kind of products. Some print produced objects are understood and exchanged as a product; others are part of a provided service. In any way, these objects began a modification in their existence.

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# Kubit: A Responsive and Ergonomic Holographic User Interface for a Proxemic Workspace

**Jed Looker and Thomas Garvey**

**Abstract** This paper imagines how a holographic user interface would respond to the changing workspace of a travelling professional. Kubit is a conceptual holographic user interface grounded in three areas of study. Proxemics defines the difference zones of human interaction, ergonomics helps reduce the risk of developing a musculoskeletal disorder, and responsive design is a method for creating flexible content. By combining these we develop guidelines for the creation of a responsive holographic user interface. To situate Kubit in a real world scenario we develop a persona and user story. The next phase of our research will be to develop a functioning prototype for future testing.

**Keywords** Responsive design · Proxemics · 3D gestural interaction · Holographic user interface · Ergonomics

## 1 Introduction

The workspace of the travelling professional changes in size depending on their location. It could be as small as an airline seat or as large as a hotel room. Portable computing is currently limited to laptops and mobile devices, but there are emerging interactive products that may replace our small screens for a more expansive, and immersive digital experience.

The past few years have seen the rise of holographic products. These are not to be confused with virtual reality products, such as the Oculus Rift [1], that immerses the user in a 3D virtual world. Rather, holographic products splice digital graphics with the physical world [2]. This paper imagines how a professional might use an interactive holographic product as they travel from workspace to workspace. The

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goal of this paper is to investigate proxemic theory, ergonomic standards, and responsive design methods to develop guidelines for the conceptualization of an interactive holographic user interface that responds to different workspaces.

## 2 Background

### 2.1 Proxemics and Human-Computer Interaction

Hall [3] defines proxemics as the relationship between individuals and space, arguing humans use the senses to define their perception of intimate, personal, social, and public spaces–much like animals do. His findings were based on a study of ethology, art, anthropometrics, and observations of middle-class Americans, the majority of who were educated business people. The measurement of these distances are approximate, take into account cultural differences, and vary depending on personality and external factors, such as increased noise or low light. Hall defines *intimate* space as up to 45 cm, with a smaller *close* phase for activities like love making, and a larger *far* phase for activities like riding a crowded bus. *Personal* space has a measurement of up to 1.2 m, inside which individuals are not in contact, but can reach for and touch one another. *Social* space has a measurement of up to 3.65 m, with the smaller close phase the distance of casual social functions, and the larger far phase the distance of more formal business, like a discussion around a boardroom table [3] (Fig. 1).

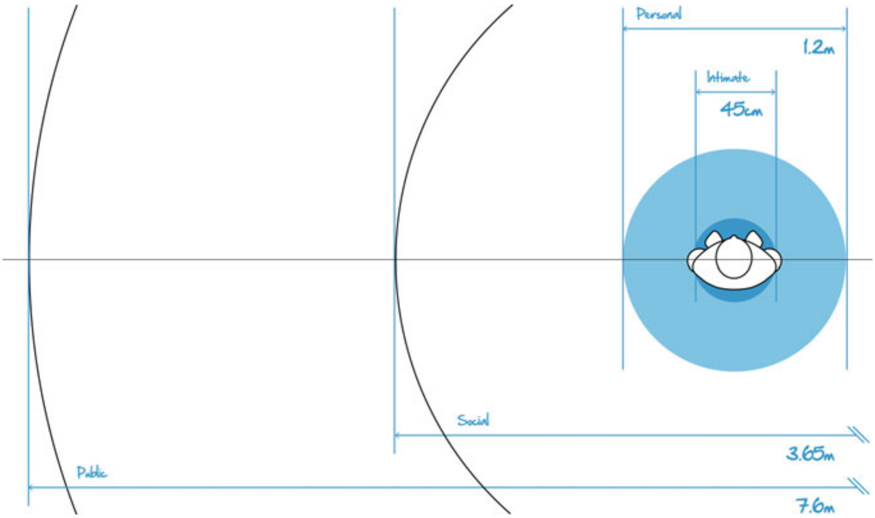


**Fig. 1** The four proxemic zones as defined by Hall [3]

In their synthesis of proxemics literature Marquardt and Greenberg [4] discuss additional theories that either expand on or differ from Hall. Petri et al. [5] and later Adams and Zuckerman [6], suggest the circular zones around an individual are actually more elliptical than circular, and longer in the front than at the back. Sommer [7] suggests the zones have more of a peanut shape, with bulbous front and back areas and sides close to the individual. According to Sommer's [7] earlier work, the orientation of two individuals to each other can affect personal space, and Ciolek [8] added social status and conversation as factors. Others suggest these zones are more fluid as individuals constantly adjust their interactions with others to achieve the optimal proxemic distance [9, 10]. Some theories argue there are no definite boundaries to these zones, but rather sensory input changes over distance [11, 12]. Lastly research into Facing Formations (or F-formations) studies the orientation of individuals or a group of individuals as they stand next to and across from each other in conversation. Kendon [13] defines a series of spaces. O-space is the zone in the centre where individual personal space overlaps; p-space is the zone around the group of individuals conversing; and r-space refers to the zone outside of p-space, or the area where other individuals are excluded from the conversation. These spaces are not necessarily circular, changing depending on whether the group has an open or closed orientation with each other.

Marquardt and Greenberg [4] synthesise these theories to establish the five proxemic dimensions of their Proxemic Interaction Framework. These are: the *distance* between a user and the people, objects and devices they interact with; the *orientation* or direction a user's body or gaze in relation to a device; the *movement and motion* (and speed) of an individual in relation to a device; the *identity* of a user, other users and the devices they interact with; and the *location* and physical context of the interaction. Although intended for the development of ubiquitous computer systems and devices (interaction with various sized displays at various distances), we posit this framework might also inform the design of a responsive holographic user interface.

Several conceptual projects consider proxemics. Prante et al.'s [14] interactive art installation Hello.Wall detects the presence of users and reacts accordingly. There are three areas of interaction dependent on user distance to the display, from *cell interaction* zone (closest), to *notification* zone, to *ambient* zone (furthest). In the closest zone the user interacts with the installation with a hand help display. Vogel and Balakrishnan [15] expanded on this research to develop a gesture controlled display for both public and personal interaction. In their model the user moves through four phases towards the display. Positioned within the *ambient* phase the user is aware of the display in their peripheral vision and does not interact with it. Moving into the *implicit interaction* phase the user sees the display but does not interact with it. In the *subtle interaction* phase the user can perform basic tasks such as navigating the system, and in the *personal interaction* phase the user can touch the screen and interact with personal information. In their interactive whiteboard prototype Range, Ju et al. [16] use Hall's proxemics zones. Standing in the *intimate* zone users can interact directly with the whiteboard. In the *personal* zone users can reach and point to manipulate text, and in the *social* zone users cannot interact with the whiteboard, but they can view it.

## 2.2 Ergonomics and 3D Gestural Interaction

The relationship between an individual and space is affected by the limitations of the human body. Dreyfuss and Tilley [17] define the anthropometric range of the 5th and 95th percentiles of man, woman and child. If we average the percentiles of men and woman we find the average person can extend their arm sideways from their leg to well over their head. This kind of motion, however, would not be sustainable over a long period of time without causing biomechanical fatigue. A *comfort range* is an area of movement that can be sustained over time without putting the user at risk of developing a musculoskeletal disorder. Using the same example as before, the comfort range of the average person when extending their arm is only 30°. The authors define the comfort ranges of a multitude of movements including shoulder abduction, elbow and wrist reach and rotation, spine twist, and eye and head rotation. Maras [18] makes similar recommendations, suggesting the shoulder should not abduct more than 30° from the side, and the head should be kept as straight as possible. She also discusses the use of mats to stand on to increase blood flow.

These comfort zones are similar to the task areas developed by the the Canadian Centre for Occupational Health and Safety [19]. They define three ergonomic areas of reach for desk work based on user task. *Frequent* tasks are performed within two intersecting 25 cm half-circles from the chest and a combined width of 100 cm, and *occasional* tasks are performed within two intersection 50 cm half-circles from the chest and a combined width of 160 cm. The area outside of the occasional task area is a *non-working area* (Fig. 2).

The ergonomics of interactive systems have also been studied. Hinchley and Pausch [20], in their survey of issues related to spatial user interfaces, posit gestures

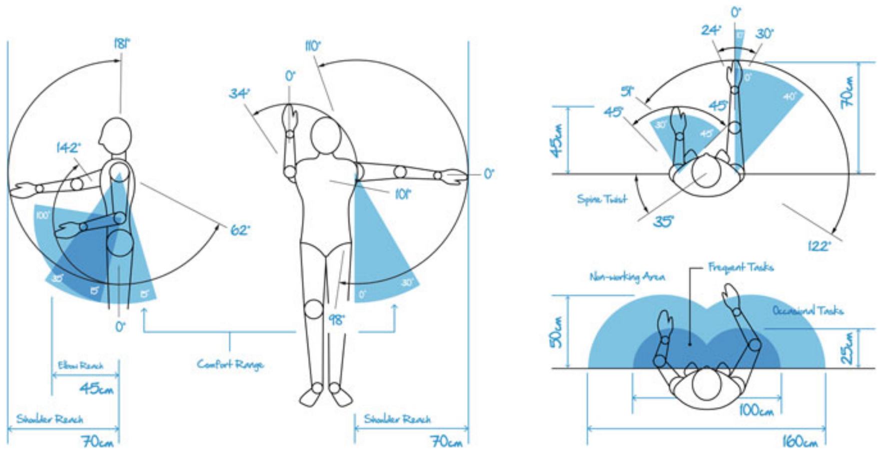


**Fig. 2** Comfort ranges defined by Dreyfuss and Tilley [17] (*left* and *top-right*), and task areas defined by the Canadian Centre for Occupational Health and Safety [19] (*bottom-right*)

in free space can cause user fatigue. To avoid poor performance and possible injury, the authors suggest the user be able to move around, and the user interface be easy to adjust and calibrate. In their conceptual project *Curve*, Wimmer et al. [21] propose an "L" shaped office workstation with user interface on both horizontal and vertical surfaces. The authors take visual and touch ergonomics studies into account when designing their desk. After reviewing the literature, they develop design guidelines for digital desks. They recommend the user interface should be of high enough resolution, large enough to accommodate a user's reach, allow for the entire display to be interactive, offer horizontal and vertical surface interaction, support the inclusion of analog media (such as books, coffee cups etc.), support the use of analog devices such as pens, mouse and keyboard, reduce the risk of developing musculoskeletal disorders by using workplace ergonomics standards, and allow users to adjust the parameters of their workstation.

In a more recent study, Bachynskyi et al. [22] thoroughly investigate the biomechanical performance of 3D gestural interaction. Their study used motion-capture biomechanical simulation to accurately capture and analyse an athlete's dominant arm movement when pointing in three dimensional space. The resulting dataset provided an estimate on energy expenditure and fatigue, and was used to inform several case studies. The placement of the user interface is a balance between usability and ergonomics. According to the authors the optimal virtual keyboard is 70 cm × 21 cm, placed below the user's line of sight and reachable with arm bent. Although the interactive areas of a public display can be quite large, interaction with arm raised can lead to fatigue over prolonged use. The favorable position of interactive content is therefore lower, about shoulder height and at arms reach from the user.

### 2.3 Responsive Design and Gestural User Interfaces

The mobile market was disrupted with the launch of the iPhone in 2007. It may not have been the first smartphone (now simply referred to as a mobile device), but it was the first to successfully appeal to a mass audience. Google responded by releasing Android as an open-source operating system, providing smaller device manufacturers a means of competing with Apple. Android would eventually surpass the iPhone to control about 76.6 % of the global market by late 2014 [23]. This was a win for Google and the cementing of the mobile device as a mainstream technology. By early 2010 Apple would again innovate with the launch of the iPad, and Android tablets were soon to follow.

The adoption of mobile and tablet devices has had a profound effect on web design methodology. With the worldwide mobile market having grown by 28.2 % in 2014 [23], designers were challenged with porting web content from large desktop screens to smaller smartphone screens. One solution was to design a different version of the website for each screen size. This might work if all mobile devices were the same, but there are several versions of the iPhone, and the Android market is extremely fragmented—a website would need to be custom-tailored countless times to accommodate each of these screens, not to mention countless times again for tablet screen sizes.

Ethan Marcotte is an influential design practitioner and pivotal figure in the evolution of web design. In his seminal article *Responsive Web Design* [24], he asks "We can quarantine the mobile experience… but what's next? An iPad website? An N90 website? Can we really continue to commit to supporting each new user agent with its own bespoke experience?". He looked to architecture for a solution.

In the late sixties Nicholas Negroponte [25] introduced the idea of responsive architecture. By using sensors 'architecture machines' could literally change their space and structure to meet the changing conditions of the individual and surrounding environment [25]. The interior walls and ceiling could be reconfigured to change the context of a room, and the exterior structure could respond to changes in the natural environment. This interplay between individual and architecture inspired Marcotte's solution for designing for multiple screens. Instead of designing a separate website for each device, he argued, we could design a single responsive website that reconfigures according to a user's screen size.

Marcotte later wrote a book to define three elements of his responsive web design methodology [26]. The first element is the use of media queries, a specific line of code used by a website to detect a user's device. Media queries allow the website to deliver custom-tailored layout and content for the device it detects, thereby taking advantage of the separation of content and style inherent to HTML and CSS. For example, the layout and content for a desktop screen could be reformatted for a smaller tablet screen, and again for a smartphone screen. The second element is flexible grids. In graphic design grids are typically based on a canvas with fixed dimensions, but when working with multiple screens the canvas has multiple widths and heights. The solution is to build grids using percentages instead of pixels, and to allow them to respond to various screen dimensions. Once a screen surpasses minimum or maximum widths—or *breakpoints*—the grid can be adjusted. For example, mobile might use a 4 column grid, tablet an 8 column grid, and desktop a 12 column grid. A breakpoint would be the dividing line between each of these screens. The third element is flexible content, such as images and media, which are set to the fluid grid as percentages. Using media queries, the content can be repositioned on the grid depending on the device screen size. For example, a row of 4 boxes for a desktop screen could be reconfigured to be 2 columns and 2 rows for a tablet screen, and reconfigured again to be 1 single column of 4 boxes for a mobile screen (Fig. 3).

This responsive design methodology has been applied to conceptual user interfaces. In their study, Harrison and Dey [27] observed how people lean into their displays many times a day to better see text and images. As a solution they developed *Lean and Zoom*, a user interface that zooms content in and out in

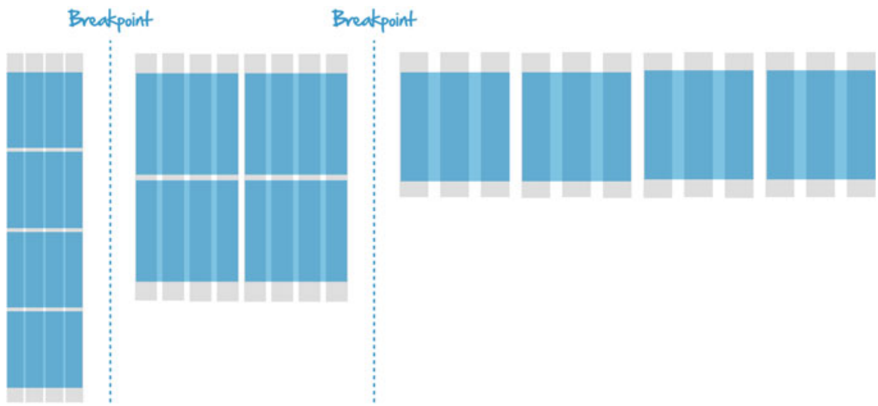


**Fig. 3** Responsive design methodology using flexible grids and breakpoints [26]

response to a user learning towards or away from their display. Ballendat et al. [28] consider a similar approach when designing their conceptual entertainment system. The user activates the film preview thumbnails by entering the room. As the user moves towards the screen the thumbnails decreases in magnification, revealing more content. After selecting a film, the user moves away from the system and sits on the sofa, at which time the selected film starts playing. Sukale et al. [29] expanded on both approaches to conceptualize a web browser that responds to the user's location in relation to their display. Their prototype uses breakpoints between *near*, *medium* and *far* distances to change the layout of a web page based on user location in relation to their desk.

# 3 Kubit: A Responsive and Holographic User Interface

## *3.1 Conceptual Guidelines*

Drawing from the literature on proxemics, ergonomics, and responsive design, we have established the following guidelines to inform our concept design, which we have affectionately named Kubit*.

1. Hall's proxemic zones are used to define the default zones
2. The proxemic zones can fluctuate in size and shape
3. 3D gestural interaction follows ergonomic guidelines and standards
4. The user can position holograms anywhere within the zones
5. All holograms are interactive
6. The threshold between zones defines responsive breakpoints

7. Grids will increase or decrease in number as they pass breakpoints
8. Content will increase or decrease in size as it passes breakpoints

*1 cubit is approximately 45 cm, or the size of Hall's intimate zone. The K is a reference to a kilobit, and the digital nature of our concept.

## 3.2 Interaction Design

Kubit would be designed within the Proxemic Interaction Framework [4], would use technology similar to the Proximity Toolkit [30], and would render holograms with hardware such as the Microsoft Hololens [31]. Kubit would be aware of a user's orientation and location, distance from objects, and movement. To borrow from the world of mobile products, we might imagine each Kubit hologram as an individual app, each with a specific task. For example, one holographic app (hereafter simply referred to as an app) might be a calendar and another a music player. Apps would render on or within the proxemics zones, and would adhere to the proxemic, ergonomic, and responsive guidelines as described above (Fig. 4).

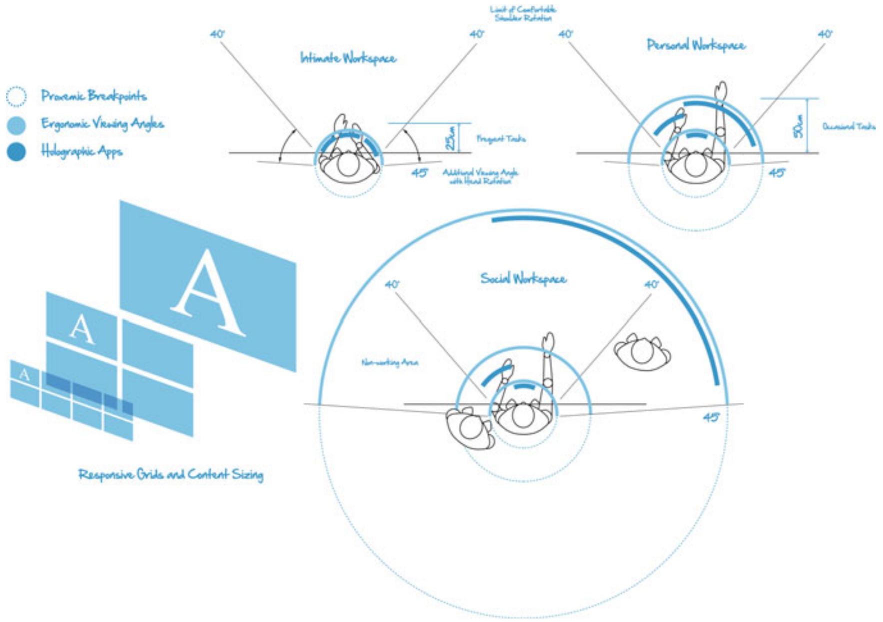


**Fig. 4** Kubit uses proxemics to define responsive breakpoints and workspaces. Grids *decrease* in number as they pass breakpoints outward. Content *increases* in size as it passes breakpoints outward. Apps can be positioned across workspaces

# 4 Discussion

## *4.1 Persona and User Story*

To situate Kubit in a real-world scenario we have developed the following persona and user story. Sarah is an art director at an ad agency. She is flying to Berlin to pitch a series of event posters to her client. In transit she makes last minute edits to the posters while listening to music. She chats with her photographer and writer about the updated source files, which she has open for reference. Time is tight, and Sarah works wherever she can, including her airline seat, airport terminal, and hotel room before the meeting.

The areas used by Sarah to work while on the road are similar to Hall's proxemics. Airline seats are typically small, with individuals often touching elbows on shared armrests. If we were to overlay Hall's zones onto the average economy seat chart, we would find individuals inside of each others intimate space. Sarah would not have much room to work on the plane. The airport terminal and lounge would have slightly more room to work, perhaps as much as the personal zone, and the average hotel room size is at least as large as the social zone, if not larger, with plenty of room to spread out while working. We will refer to these zones as the intimate, personal and social workspaces.

When flying Sarah is limited to interacting with apps within the intimate workspace. Because space is limited she has to stack apps on top of each other, using the one closest to her and retrieving others from deeper layers when needed. The apps are placed below her line of sight and are easily accessible with arm bent. After landing and waiting for her connecting flight, Sarah works in a lobby seat near her gate. Kubit detects the additional space and makes the personal workspace available. Sarah takes the apps that are not essential and pushes them to the personal workspace. As the apps pass the intimate/personal threshold they respond by reducing grids and increasing the size of graphics and typography. Sarah occasionally extends her arm to reach into the personal zone to interact with specific apps, like the music player. After arriving in Berlin, Sarah spends the rest of the evening perfecting her presentation slides. Kubit has detected the size of the room and has made the social workspace available. Sarah edits her slides in her intimate workspace, but has pushed a preview of her presentation out to the social workspace. Tired from her long trip, she reaches out to her music player in the personal workspace to change the tune to something more soothing. At the end of the night she uses a gesture to retrieve the presentation back to the personal workspace, and puts Kubit to sleep.

## *4.2 Future Research*

The next phase of our research will be to build Kubit as a functional prototype and test the tasks identified in the user story as described above.

## 5 Limitations

Visual acuity was not discussed in great detail, and would be a factor in creating a layered holographic user interface. Studies have shown the perceptual quality of holograms remains complex [32]. Also, the technology used to create the holographic overlay will need to be studied before a prototype is proposed.

## 6 Conclusion

As a conceptual exercise this paper presents Kubit, a responsive holographic user interface based on three areas of research. Proxemic theory is used to define the intimate, personal and social zones of the user, and locate and orientate them as they move through their surroundings. Ergonomic standards are referenced to reduce the risk of the user developing a musculoskeletal disorder while interacting with the holograms. A responsive approach to design is taken to optimize the holograms as they respond to the different proxemic zones. After developing guidelines for designing Kubit, we propose the individual holograms would be like mobile apps, each with their own tasks. We develop a user story to define the proxemic workplace of a travelling professional, and provide an example of how this user can move apps between workplace zones as they appear.

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# The Development of Design Specification for Ergonomics Sofa in Malaysia

**Khairul Azhar Mat Daud, Ahmad Rasdan Ismail, Suriatini Ismail and Nik Zulkarnaen Khidzir**

**Abstract** To design and develop a sofa that has ergonomic features, designers should identify the features are need to design sofa. To knowing and understanding the appropriate design which concurrent with market demand, the designers must to conduct market survey among users whose are need and use sofa. The desires of users to have a sofa that has the characteristics of safety and health should be examined from a variety of factors. The draft and sketching sofa with an attractive design and meet customer requirements, design specifications need to be developed first. This paper will explain how to develop sofa's design specifications which have ergonomic features for users in Malaysia. Market survey was organized among three main groups of sofa's user that is sofa users, sofa makers and sofa retailer.

**Keyword** Design specification · Ergonomics sofa · Sofa users · Sofa makers · Sofa retailers

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## 1 Introduction

Sofa is a chair that uses to sit comfortably. Sofa usually placed in the guest room, whether in the office or at home. Use sofa very noticeable when the user uses sofa to sit down for relaxing of in conversation and discussion. Sofa also been placed in the waiting room at service center, clinics, centers and professional consultations and so on. Use sofa very significant to the human being activities. However the reality of concepts and methods in industrial design in Malaysia at present is more focused on designing a beautiful, inexpensive and simple [1]. Therefore, the designing of sofa which is emphasized the ergonomic features is very crucial. [2], stated that design concept initially was considered to be the most sensitive design, critical and difficult to create a product. [3], asserted that affecting the cost, robustness, manufacturing methods in the design and development of products. Designing a sofa with ergonomic features will help a sofa designer to develop a comfortable sofa and meet the shape of the human body posture. Most available sofa in the market was imported from other countries such as China, Italian, Indonesian and German. The conceptual of imported sofa is representing of their country. When, in aspect of size and design it is more inclined to the size of the user in their respective countries [4]. From observation, most of the European sofa has a big size rather than sofa from Asia countries such as China and Indonesia. The materials which is use to make sofa also very disparate regarding to countries where it's came from.

In designing the sofa, design and size should refer to the size of the body posture of the local community. Most of the sofa in the market is not in accordance with local community body posture. Sofa made without referred to the size of the user's body will cause consumption to be less comfortable sofa. Ergonomics is dependent on the ability of people to design product by adapted the physical characteristics of humans in aspect of human activities, views, thoughts and others in the current situation [5]. The uncomfortable sofa will distract the users to use it comfortably. Therefore, it is very important to maintain the comfort of the user to use the sofa to sofa design appropriate to the needs of the human body. In addition, the sofa can also be a seats that will help user to maintain the health of the human body and to preventing it from occurring internal stress which is contribute internal body pain such as back pain, tension veins and depression due to use the uncomfortable sofa.

## 2 Design Specification

The process of designing a sofa made after all relevant specific data was collected. The product that was designed must be meets the needs of consumers. Therefore, to ensure the development of products meet the ergonomic criteria and users demand, the design of sofa must be attractive and meet the demand of consumers [6].

Currently, we have a various types of sofa in the market. Sofa designs in the market were looking good and almost consider with the esthetic value. Currently, in the market we didn't have any sofa which is concern about the ergonomic features in their design. Almost sofa was designing with designer imagination and perception. Beauty and looking good is the most important factor to the designer when they are design sofa [4]. Designers are not really concern about ergonomic factors. Therefore, this study is very crucial in order to provide an ergonomic sofa according to the size of the human body posture. Through this study, is expected to create a new market segments for sofa to those who care and emphasize with health will grow in Malaysia. To develop of the sofa based on human body posture will derived from Malaysians anthropometric data.

## 3 Conceptual Framework

See Fig. 1.

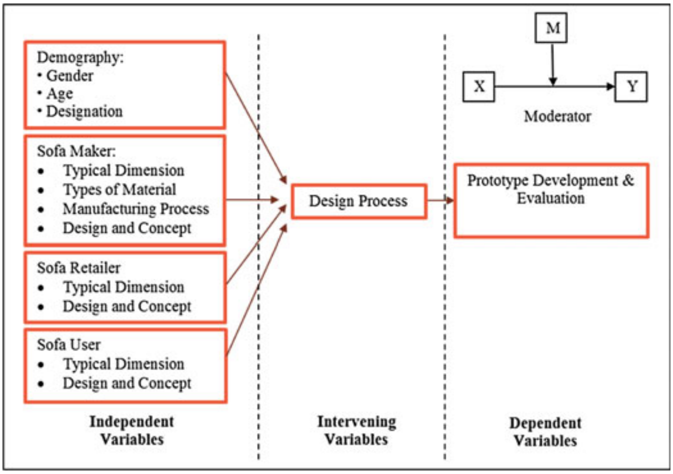



**Fig. 1** Conceptual framework

## 4 Method of Data Gathering

Among the most important elements in a study is a method to get the data. The survey data can be obtained from various methods such as observation, document analysis, questionnaires, interview and so on [7], asserted that research methods are the specific research techniques that are used in a research methodology to collect and analyze data in order to find answer to the research questions. The techniques include observations, document analysis, questionnaires, interview and so on. To develop design specifications for ergonomic sofa for Malaysians, data will be

**Table 1** The research matrix

| Data needed | Research questions | Technique of data gathering | Technique of data analysis |
|---|---|---|---|
| 1. Design requirements | Are user centered "smart seat" based on health can be designed?<br>• How to design a sofa-based health? | 1. Questionnaire<br>2. Interview<br>3. Document analyses | Descriptive |
| 2. The ergonomics concept | Do sofa that has good ergonomics and safety can be produced?<br>• What are the features of ergonomic design for sofa?<br>• What are the features of safety to design ergonomic sofa? | 1. Questionnaire<br>2. Interview<br>3. Document analyses | Descriptive |
| 3. Concept of design and statement of design | Do sofa with light criteria and new material can be developing?<br>• How to design a light weight sofa?<br>• What type of suitable materials were used to develop the frame of the sofa?<br>• What type of suitable sponge materials were used in sofa?<br>• What type of suitable spring materials were used in sofa?<br>• What type of suitable fabric materials were used in sofa? | 1. Questionnaire<br>2. Interview<br>3. Document analyses | Descriptive |
| 4. The manufacturing concept | Does the manufacturing and assembly process can be enhanced?<br>• How manufacture and installation of sofa was currently practiced? | 1. Questionnaire<br>2. Interview<br>3. Document analyses | Descriptive |
| 5. The development of sofa prototype | Do sofa prototype can be developed and marketed to the international stage? | 1. Questionnaire<br>2. Interview<br>3. Anthropometric | Descriptive |

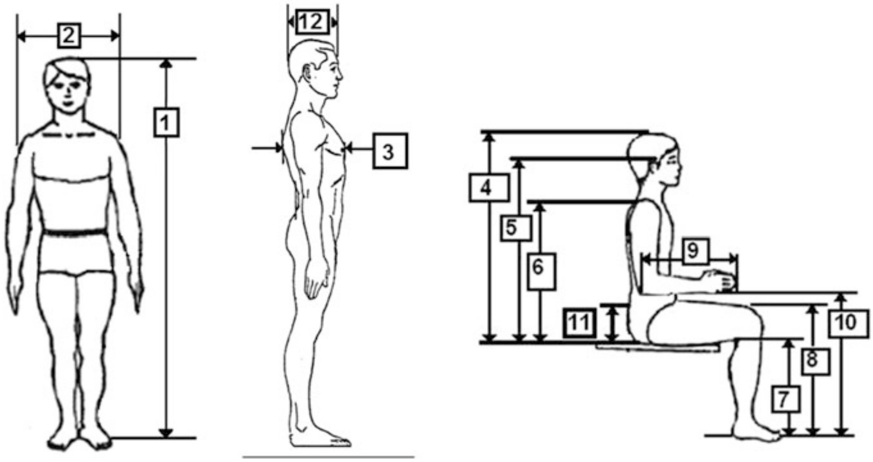
getting through questionnaire, interview, observations, audio-taping and video. To get the data in focus and proper, a research matrix was developed. The research matrix is as shown in Table 1.

## 5 Anthropometry Data for a Total of 1485 Subjects (mm)

See Table 2.

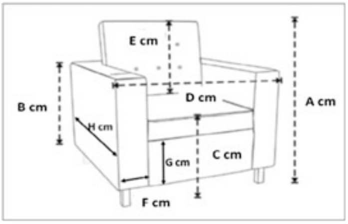
**Table 2** Anthropometry data for a total of 1485 subjects (mm)

| No | Dimensions | Male | Female | Status |
|---|---|---|---|---|
| | | 50th | 50th | |
| 1 | Stature | 1636.91363 | 1634.500357 | Not available |
| 2 | Shoulder breadth | 456.9163293 | **457.9771265** | Available |
| 3 | Chest depth | 215.0053981 | 216.2802001 | Not available |
| 4 | Sitting height | **836.3461538** | 831.9728377 | Available |
| 5 | Sitting eye height | 721.8151147 | 717.8734811 | Not available |
| 6 | Sitting shoulder height | 550.7381916 | 546.575411 | Not available |
| 7 | Popliteal height | **435.6491228** | 436.1393853 | Available |
| 8 | Sitting knee height | 495.4008097 | 495.4496069 | Not available |
| 9 | Forearm hand length | **444.8502024** | 445.645461 | Available |
| 10 | Sitting elbow height | 217.8677463 | **216.8184417** | Available |
| 11 | Thigh clearance | 187.8690958 | 189.2430307 | Not available |
| 12 | Head length | 199.6707152 | 199.8298785 | Not available |




See Table 3.

**Table 3** The general specification to design an ergonomic sofa

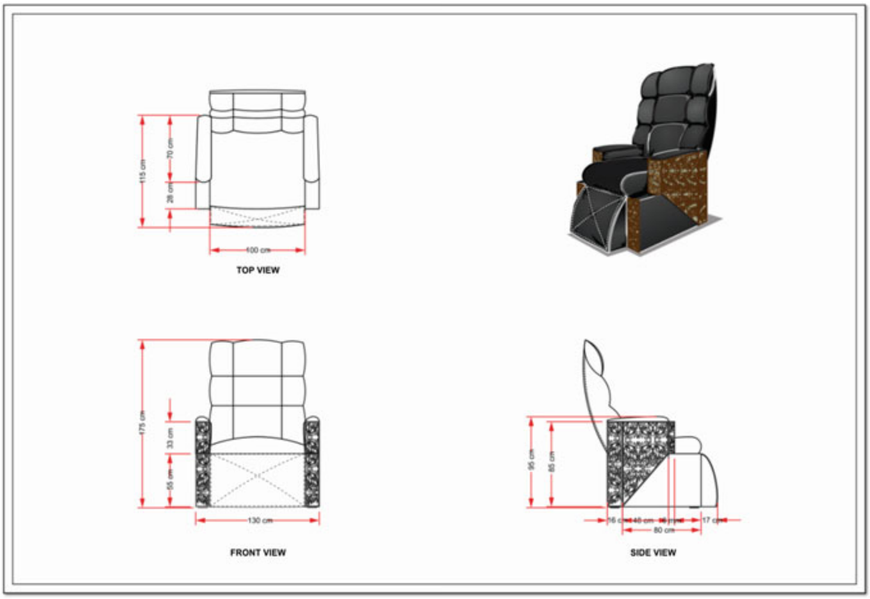



| Typical dimension | Typical sofa dimension | Anthropometric dimension |
|---|---|---|
| A = E + C | 100 cm | 127 cm |
| B = 10 | 48–55 cm | 21.6 cm |
| C = 7 | 45–52 cm | 43 cm |
| D1 = NA | 50–52 cm | – |
| D2 = 2 | 42–44 cm | 45 cm |
| E = 4 | 58–71 cm | 83 cm |
| F = NA | 15–20 cm | – |
| G = NA | 23–26 cm | – |
| H1 = NA | 78–92 cm | – |
| H2 = 9 | – | 44 cm |

| *Sofa's structure* | *Type of material* |
|---|---|
| Frame | Ply wood |
| Spring system | Eight-way hand tied spring coils |
| Fundamental sponge | High density polyester sponge |
| Middle sponge | High density polyester sponge<br>or<br>High density sponge |
| Wadding | High density sponge |
| Natural fabric | Leather |
| Synthetic fabric | Polyester |
| *Sofa's conceptual* | *Basic criteria of design* |
| Concept | Modern |
| Arm rest | Need |
| Back rest | Need |
| Head rest | Need |
| Leg rest | Need |
| Color | Black |
| Texture | Leather |
| Price expectation | RM 5000.00–RM 8000.00 |
| *Malaysia Identity* | *Criteria Need* |
| Carving | Modern |
| Malaysia concept | Need |
| Color | Need |
| Pattern of texture | Need |
| Mix material | Need |

## 6 Selected Design/Final Drawing

## 7 Technical Drawing



## 8 Conclusion

This paper was elaborating the means to develop design specification for Malaysians ergonomic sofa. The development of design specification before through the process of sketching and designing particular product as ergonomic sofa is mostly crucial to a designer. Designer must determine and identify every single of features were demand by users before design a particular product as ergonomic sofa. To develop design specification for ergonomic sofa, designer must organized market survey to meet customer's need. A great design is a designing that have a great ability to meet and full fill all customers requirement.

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# Smartphone Ergonomics: A Proposal for Older People

**Javed Anjum Sheikh, Beenish Zafar, Anam Pervez and Zunaira Ilyas Bhutta**

**Abstract** A topic specifically noteworthy here is acceptance of recent and latest smartphone technology by the older people. The expanding progress and utilization of technology presents challenges for older users in using new technology. Less ergonomically designed Smartphones are as of now entangled to alter for ease of use needs older users, they feel uneasiness. In this research a broadly used Technology Acceptance Model (TAM) is applied to investigate the basic Human factors which may have significant effect on smartphone acceptance and behavioral intention among older individuals in Pakistan. A new model, Smartphone Acceptance Model for Pakistani Older People (SAMPOP) in our future work which clarifies the most critical elements responsible for complete adoption and acceptance of smartphones by the older people.

**Keywords** Ergonomics · Smartphone · Technology acceptance model · Usability

## 1 Introduction

In the 21st century, there will be generally older people around [1] and on the other side, the innovation is growing an extraordinary rate. Combined with this explosive development in technology is the ageing of the population. Accordingly, it is of basic significance to comprehend the factors that impact the acceptance of technology by older people. The cell phones these days are tended to as 'smartphone',

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as they offer more propelled computing power, connectivity, usability and accessibility than a present mobile phone [2]. The rate of individuals having a smartphone is progressively growing, despite the fact that most of them do not use many of these advanced functions. Pakistan is additionally in accordance with the rest of the world in development of cellular phone industry. On the list of top 10 nations, Pakistan positioned eighth with biggest number of mobile phone subscribers [3, 4].

There has been a synchronous improvement in society between the growth of older populations and the prevalence of innovation [5]. Older adults tend to use their smart phones for generally restricted because of various constraints [6]. The restricting components incorporate physical and cognitive ergonomics, technology awareness, social structure, individual ergonomic variables etc. which may builds the digital divide between the older and younger generations. To decrease this generation gap smartphones need to furnish great ease of use regarding the effectiveness, efficiency and users' satisfaction [7]. Older people appear to have been a neglected user group in design of smartphones in Pakistan. In this regards to examine the individual acceptance behavior on Information technology, a Technology Acceptance Model (TAM) [8] is an appropriate option.

In this research we use the terms senior, elderly, older adult, and "older people" to refer to individuals above 45 years old. This research will present the older users perspectives and experiences toward smartphone use, their inclinations and likings, their concerns about acceptance of smartphones. This study will advance investigate real recommendations to design ergonomically fit smartphones for older people. Questionnaire survey would be conducted to record the preferences of older people for design layout. First part of this research results will provide available solution to designers and developer to incorporate the preferences of older people. Part 2 of this research discusses the work related to developing Smartphone Acceptance Model for Pakistani Older People (SAMPOP) based on constructs of Technology acceptance model and incorporating the accompanying additional constructs: social Influence, Enjoyment, technology awareness, self-actualization, perceived ease of use, perceived usefulness and behavioral intension. The crucial personal circumstances of Pakistani older people who are smartphone users will also be discussed.

## 2 Literature Review

Although numerous studies have been undertaken internationally yet minimum consideration has been given on this issue in Pakistan. An overview of existing literature of older adult and smartphone use will first be covered before moving into the particular research questions. This research closely investigated the role of older adult personality, perceived usefulness and ease of use of technology, self-efficacy, and attitude toward using technology on technology adoption [9]. The way in which older adults perceive innovation to be valuable may rely on the environment they grew up in. The technology acceptance model [8] served as a reference model for this research. This section presents the literature review. The main focus of Sect. 2 lays the introduction about the interaction amongst individuals and machine, what the usability is all about, ergonomics in smart phone design, confinements of aging and technology acceptance model, which is the reference model for this research.

Usability refers to techniques for enhancing convenience during the design procedure [7]. International organization for Standardization (ISO) defined the usability as [10, 11]: “The effectiveness, efficiency and satisfaction with which specified users can achieve specified goals in particular environments”. In short term, usability is about giving clients the best capacities to complete tasks. The meanings of the three key terms are [12]: Effectiveness is the exactness and fulfillment with which particular users accomplish their own objectives with the system; Efficiency is the assets consumed in relation to the precision and completeness of goals accomplished; Satisfaction is the solace and adequacy of the system to the clients and other individuals influenced by its use.

Cellular phone industry in Pakistan. A variety of ICT products accessible, the mobile phone is the one most generally used by older adults as a part of everyday life. Mobile phones achieved so much prevalence since they permit individuals to stay in touch and have simple access to information anyplace and at whatever time [13]. Previous studies have demonstrated that older people know about and willing to use various types of technology, particularly mobile phones, which can possibly show signs of improvement for older people [14]. Network coverage of right around ninety percent of the aggregate populace of Pakistan has made mobile industry considerably more attractive for foreign investment [15] Growth of cellular phone industry in Pakistan is as incredible as in developed countries and particularly in star Asian countries. There will be 40 million smartphones in Pakistan by December 2016, as indicated by market estimates, in light of current patterns in the e-commerce sector [16].

### *2.1 Ergonomics and Gerontechnology*

Ergonomics also known as comfort design is the study of designing equipment and devices that fit the human body and its intellectual capacities [17]. Diverse ergonomic Risk factors exist like physical factors, cognitive factors and so on that should be considered in smartphone designing. Mobile phone and tablet technology, like desktop PC and portable workstations, can posture musculoskeletal stress if ergonomic practices are not kept [18]. Physical ergonomics in touchscreen interaction have looked at comfort, user inclinations, joint points, stances and muscle use. Physical ergonomics is concerned with the human body’s reactions to physical and physiological loads [19]. Cognitive ergonomics, also known as engineering psychology, concerns with mental procedures for example recognition, consideration, discernment, motor control, and memory storage and retrieval as they influence connections among people and different components of a framework [20].

Gerontechnology is a comparatively new field that links gerontology, ergonomics and technology in the design of products and environments. Gerontechnology is functional in five foremost areas of design: prevention, remuneration, enhancement, research, and help to caregivers. Prevention is the most capable and novel of these applications since it recommends that aging might be adjusted by overhaul of the environment, products and services [21, 22].

### 2.2 Limitations of Aging

Older people accept and adopt technology when it lives up to their requirements and desires [23]. Issues of the Elderly can be sorted coarsely into cognitive, inspiration, physical and perception [24, 25]. Most side effects related with aging that are pertinent to ergonomics can either be prohibited or possibly effectively accommodated, so they require not get to be debilitating. Basic impacts of aging include:

Cognitive Behavior: Cognitive abilities include everything associated to thinking, decision making and memory. Intellectual changes are unavoidable parts of aging that backs off the human performance slowly but surely and makes a person feel as if the external events have started to execute with more acceleration. Incessant complaints from elders about faster evolving subtitles, events being fleeting, time appearing to flow faster than before, all are consequences of cognitive changes that happen with the age [26]. It has been observed that as people get old there memory gets frail. Memory is a gathering of complex procedures inside the human mind that is in charge of the storage and recovery of all the information that we memorize [27]. As psychological capacities decreases with age, this appears to have an influence on the performance of older adult users when using intelligent technology [28]. Fisk has characterized the working memory as the capacity of our brain to keep the information alive or active for as long as we are working on it [29]. The limit of this working memory is constrained [30], yet for the most part the constraint accompanies the age

**Physical, Psychological and Social Behavior**: In old age, individuals need to manage impediments that they begin to experience in various periods of life and need to grapple with numerous sorts of misfortunes [31]. In physical changes **Vision** also influenced by aging. Visual hindrance takes several forms, from partial loss of vision through to complete blindness. Similarly the steady loss of **hearing** is most normally related with aging [32]. The weakness of fine motor skills is likewise frequently a factor in older peoples' unwillingness to acknowledge mobile phones [25].

Apart from the changes that elders confront and have to deal with correlated to their bodies and capabilities, they need to face and manage with the losses of their dear ones [33]. Older people choose fewer friends and more rich relationships with sincerity and honestly instead of more number of friends [34].

**Motivational issues**: Older adults are really persuaded to use mobile phones, when they are feeling contented and informed about the subsequent advantages. Absence of learning skills and poor proficiency rate additionally de-propels the older users [35]. Wellbeing and security have also been perceived as the most critical reasons behind motivating mobile phone adoption among older individuals [36].

## *2.3 Technology Acceptance Model*

The factors impacting use of technology have been studied broadly. Several models have been proposed to clarify innovation acceptance behavior, including the theory of reasoned action (TRA) [37–39], the technology acceptance model (TAM) [8], the technology acceptance model 2 (TAM2), and the unified theory of acceptance and use of technology (UTAUT) [40]. Technology Acceptance Models attempted to distinguish and examine Behavioral Intensions of users in utilizing technology. In [8] Davis proposed TAM to address why users accept or dismiss technology innovation. This model gives a theoretical premise to determination of the outside variables that influence users' internal beliefs, attitudes, and intentions, thereby affecting users' information technology usage behavior. It is one of the most cited and influential models that aim at explaining the factors that decides Information Technology (IT) acceptance [41–43]. This model incorporates five factors: perceived ease of use, perceived usefulness, behavioral intention, attitudes and actual usage (Fig. 1).

**Perceived Usefulness (PU)**: PU is characterized as the degree to which an individual considers that he or she would benefit from using technology [44–48].
**Perceived Ease of Use (PEU)**: PEU is defined as the degree to which an individual believes that using the system will be free of exertion [48–51].
**Attitude towards Using (ATU)**: Attitude is furthermore characterized as 'the user's attractive quality of his or her utilizing the system, Perceived usefulness (PU) and perceived ease of use (PEU) are the sole determinants of demeanor

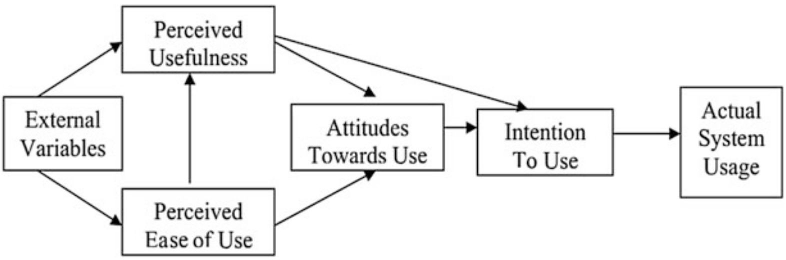


**Fig. 1** Final version of technology acceptance model (TAM)

towards the technology system [48]. The original TAM, indicated that attitude applies a positive beneficial outcome on the behavioral intention [49, 52].
**Behavioral Intension to Use (BITU)**: According to [53] the behavior intention is defined as a measure of potency of one's aim to perform a definite behavior. It is predicted by attitude towards use (A) collectively with perceived usefulness (PU) [52].

External Variables: TAM also expect some 'external factors' such as user contrasts (intellectual style and other personality variables), system attributes, and task characteristics, the effects of which are completely intervented by PU and PEOU [54]. Technology acceptance Model (TAM) is a users intension based model which address the issues of users attitude towards use of technology and its genuine use [55].

## 3 Problem Statement

The older people in under developing countries like Pakistan are the only growing age group that favored the use of smartphones mostly for the most part to perform basic functions. Distinctive characteristics and ergonomic risk factors for every individual older user affected their performance and cause obstacles in acceptance of technology as compared to young adults. The available smartphones did not address the issues and expectations of older people and don't address the restrictions of aging which lessen their fulfillment against technology acceptance.

## 4 Proposed Method and Findings

This research is based on two parts: one is Adoption and acceptance phase of smartphone by elderly and second is a model SAMPOP that will be proposed in future. In second phase we will be investigating the key factors that have an impact on the adoption of smartphones included conducting research on technology adoption model (TAM) by developing and administering a questionnaire. Structural Equation Modeling will be used to confirm a proposed smartphone acceptance model based on Technology Acceptance Model (TAM).

**First Phase includes**:

- What are the demographic factors that add to expectation to use a smartphone?
- What are Individual factors (physical and cognitive ergonomics, aging limitations) influences the usability of smartphones?
- What are the factors influencing the Adoption and acceptance Phase?

**Second Phase includes (Future Work)**:

- Is a social influence factor contributed to intention to use a smartphone?
- Is a self-actualization factors that contribute to intention to use a smartphone?
- Is enjoyment factors that contribute to intention to use a smartphone?
- Is Technology awareness factors that contribute to intention to use a smartphone?
- Is Perceived Ease of Use (PEU) has a positive significant relationship towards smartphone acceptance and adoption?
- Is Perceived Usefulness (PU) has a positive significant intention to use a smartphone?

For the first phase of study a structured questionnaire and face to face individual interviews have been conducted with older adults (over 45) to collect the information. We interviewed 100 elderly people. Their demographic details are given in Table 1. Total we interviewed 59 men and 41 women. All of them were educated and had easy access to technology. Out of the 100 people that were interviewed, 18 of them were still using feature phones, 7 males and 11 females.

In second part of questionnaire we asked the people to rate functionalities according to the frequency of their use and their knowledge about them. In Table 2, we have listed the functionalities with frequency of their use. Most elderly people can use the basic functionalities like calls, sms, calendar and clock.

We have based our findings on the basic TAM [32] model. At this stage we are particularly interested in investigating the most basic factors recognized by TAM which are Ease of Use and Perceived Usability and other construct measurements

**Table 1** The profile of respondents: gender, age group, education

| Category | | Number of respondents | Percentage (%) |
|---|---|---|---|
| Gender | Male | 59 | 59 |
| | Female | 41 | 41 |
| | Total | 100 | 100 |
| Age | 45–50 | 7 | 7 |
| | 50–60 | 47 | 47 |
| | 60–70 | 38 | 38 |
| | 70+ | 8 | 8 |
| | Total | 100 | 100 |
| Education | Elementary school or below | 0 | 0 |
| | High School | 7 | 7 |
| | Diploma/certificate | 4 | 4 |
| | Bachelor’s degree | 47 | 47 |
| | Master’s degree | 31 | 31 |
| | Others | 11 | 11 |
| | Total | 100 | 100 |

**Table 2** Features of smartphone used by respondents

| Features of a smartphone | Frequency |
|---|---|
| Calling | 95 |
| Display date and time | 53 |
| Emergency button | 54 |
| Alarm | 47 |
| Camera | 91 |
| Calculator | 65 |
| Text messaging | 67 |
| Mini games | 12 |
| Calendar | 72 |
| Contact pictures | 54 |
| Blue tooth | 6 |
| Radio | 8 |
| Wi-fi Internet | 68 |
| Torch | 87 |
| MP3 ringtones | 45 |
| Playing MP3 songs | 33 |
| Playing Videos | 51 |
| Notepad | 4 |
| Global positioning system | 5 |
| E-mailing | 53 |
| Sound recording | 32 |
| Mobile banking | 68 |

(social influence, self actualization, enjoyment, technology awareness) will be investigated in future and SAMPOP model based on TAM will be proposed.

## 5 Future Work

In future based on these findings we will enhance our work by developing Smartphone Acceptance Model for Pakistani Older People (SAMPOP) based on constructs of Technology acceptance model and incorporating the following additional construct measurements: social Influence, Enjoyment, technology awareness and self-actualization, perceived ease of use, perceived usefulness and behavioral intension. The basic personal circumstances of Pakistani older people who are smartphone users will also be discussed. Expected result of research will be:

- Identification of key factors that have impact of smartphone acceptance and adoption by older people in Pakistan
- Usability characteristics will enhance the preference of older people for using basic mobile phone functions.

- Guidelines for ergonomically fit smartphone design for older people in context of Pakistan
- A proposed model (SAMPPOP) based on existing technology acceptance model (TAM) in context of Pakistan.

## 6 Conclusion

In this research we will investigate the issues confronted by the elders in adopting and accepting smart phones. We are considering existing technology acceptance and adoption models and extracted the fundamental factors especially from TAM. These and other distinguished factors will be confirmed by conducting interviews from the elderly. Our main contribution in this research will be the proposed SAMPOP which clearly describes the factors affecting the adoption and acceptance phases. This model can be exceptionally useful for designing user friendly smartphones for elders which can be totally adopted and accepted by the elders.

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