Advances in Intelligent Systems and Computing 486

Marcelo Soares
Christianne Falcão
Tareq Z. Ahram *Editors*

Advances in Ergonomics Modeling, Usability & Special Populations

Proceedings of the AHFE 2016 International Conference on Ergonomics Modeling, Usability & Special Populations, July 27–31, 2016, Walt Disney World®, Florida, USA

Springer

Advances in Intelligent Systems and Computing

Volume 486

About this Series

The series "Advances in Intelligent Systems and Computing" contains publications on theory, applications, and design methods of Intelligent Systems and Intelligent Computing. Virtually all disciplines such as engineering, natural sciences, computer and information science, ICT, economics, business, e-commerce, environment, healthcare, life science are covered. The list of topics spans all the areas of modern intelligent systems and computing.

The publications within "Advances in Intelligent Systems and Computing" are primarily textbooks and proceedings of important conferences, symposia and congresses. They cover significant recent developments in the field, both of a foundational and applicable character. An important characteristic feature of the series is the short publication time and world-wide distribution. This permits a rapid and broad dissemination of research results.

More information about this series at http://www.springer.com/series/11156

Marcelo Soares · Christianne Falcão
Tareq Z. Ahram
Editors

Advances in Ergonomics Modeling, Usability & Special Populations

Proceedings of the AHFE 2016 International Conference on Ergonomics Modeling, Usability & Special Populations, July 27–31, 2016, Walt Disney World®, Florida, USA

Springer

Editors
Marcelo Soares
Federal University of Pernambuco
Recife
Brazil

Tareq Z. Ahram
University of Central Florida
Orlando, FL
USA

Christianne Falcão
Catholic University of Pernambuco
Recife
Brazil

ISSN 2194-5357 ISSN 2194-5365 (electronic)
Advances in Intelligent Systems and Computing
ISBN 978-3-319-41684-7 ISBN 978-3-319-41685-4 (eBook)
DOI 10.1007/978-3-319-41685-4

Library of Congress Control Number: 2016944177

Printed on acid-free paper

This Springer imprint is published by Springer Nature
The registered company is Springer International Publishing AG Switzerland

Advances in Human Factors and Ergonomics 2016

AHFE 2016 Series Editors

Tareq Z. Ahram, Florida, USA
Waldemar Karwowski, Florida, USA

7th International Conference on Applied Human Factors and Ergonomics

Proceedings of the AHFE 2016 International Conference on Ergonomics Modeling, Usability & Special Populations, July 27–31, 2016, Walt Disney World®, Florida, USA

Advances in Cross-Cultural Decision Making	*Sae Schatz and Mark Hoffman*
Advances in Applied Digital Human Modeling and Simulation	*Vincent G. Duffy*
Advances in Human Factors and Ergonomics in Healthcare	*Vincent G. Duffy and Nancy Lightner*
Advances in Affective and Pleasurable Design	*WonJoon Chung and Cliff (Sungsoo) Shin*
Advances in Human Aspects of Transportation	*Neville A. Stanton, Steven Landry, Giuseppe Di Bucchianico and Andrea Vallicelli*
Advances in Ergonomics In Design	*Francisco Rebelo and Marcelo Soares*
Advances in Ergonomics Modeling, Usability & Special Populations	*Marcelo Soares, Christianne Falcão and Tareq Z. Ahram*
Advances in Social & Occupational Ergonomics	*Richard Goossens*
Advances in Neuroergonomics and Cognitive Engineering	*Kelly S. Hale and Kay M. Stanney*
Advances in Physical Ergonomics and Human Factors	*Ravindra Goonetilleke and Waldemar Karwowski*
Advances in The Ergonomics in Manufacturing: Managing the Enterprise of the Future	*Christopher Schlick and Stefan Trzcielinski*
Advances in Safety Management and Human Factors	*Pedro Arezes*
Advances in Human Factors, Software, and Systems Engineering	*Ben Amaba*
Advances in Human Factors and Sustainable Infrastructure	*Jerzy Charytonowicz*
Advances in The Human Side of Service Engineering	*Tareq Z. Ahram and Waldemar Karwowski*

(continued)

(continued)

Advances in Human Factors in Energy: Oil, Gas, Nuclear and Electric Power Industries	*Sacit Cetiner, Paul Fechtelkotter and Michael Legatt*
Advances in Human Factors in Sports and Outdoor Recreation	*Paul Salmon and Anne-Claire Macquet*
Advances in Human Factors and System Interactions	*Isabel L. Nunes*
Advances in Human Factors, Business Management, Training and Education	*Jussi Kantola, Tibor Barath, Salman Nazir and Terence Andre*
Advances in Human Factors in Robots and Unmanned Systems	*Pamela Savage-Knepshield and Jessie Chen*
Advances in Design for Inclusion	*Giuseppe Di Bucchianico and Pete Kercher*
Advances in Human Factors in Cybersecurity	*Denise Nicholson, Janae Lockett-Reynolds and Katherine Muse*

Preface

Successful interaction with products, tools, and technologies depends on usable designs and accommodating the needs of potential users without requiring costly training. This book is concerned with emerging 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—that 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.

This book is organized into seven parts that focus on the following subject matters: usability evaluation, devices and user interfaces, assistive technology and accessibility, interface design, user studies, product design and evaluation, and sustainable design. In the parts that cover devices and user interfaces and ergonomics modeling for industry, the focus is on the optimization of user devices, with an 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 on force and kinematics, physiology, and cognitive performance in the design of consumer products, tools, and workplaces is discussed. The parts that cover environmental design, product and design 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 the same time the efficiency of the system. Usability evaluations are reported for different kinds of products and technologies.

Part 1: Applied Design, Modeling and Usability Evaluation I
Part 2: Applied Design, Modeling and Usability Evaluation II
Part 3: Ergonomics and Design for All
Part 4: Ergonomics and Environmental Design
Part 5: Ergonomic Design, Assistive Technology and Accessibility
Part 6: Interface Design and Usability Evaluation for Healthcare and Safety
Part 7: Ergonomics Modeling for Industry

We hope that this book will inspire leading the reader to contemplate other questions, applications, and potential solutions in creating good designs for all. We would like to thank the Editorial Board members for their contributions.

Recife, Brazil — Marcelo Soares
Recife, Brazil — Christianne Falcão
Orlando, FL, USA — Tareq Z. Ahram
July 2016

Contents

Part I
Applied Design, Modeling and Usability Evaluation I

Evaluation of a Real-Time Feedback Solution for Ergonomic Parameters Using Smart Sensors and User Centered Design

Timm Römer, Christopher Stockinger and Lukas Bier

Abstract Musculoskeletal issues are a common problem in work life. Mental issues are rising. Employees are often not aware of the ergonomic aspects of their work, not knowing when a certain action they perform is ergonomically unhealthy. A possibility to prevent that is to assess ergonomic parameters during work and give feedback, so that the employees can learn and improve. Common systems for ergonomic assessments are often only snapshots and give no direct feedback. Therefore, this paper presents the user centered design process (UCDP) of a real-time feedback solution for ergonomic parameters that gives employees direct feedback by using the built in sensors of everyday-life technology like smartphones, smartwatches and activity trackers to monitor different parameters of ergonomics at work and show possible improvements. A corresponding App was developed as digital interactive prototype. The UCDP thereby featured several iterations with user studies and expert evaluations to ensure high user friendliness.

Keywords Ergonomic assessment · Real time feedback · Industry 4.0 · User centered design process · Monitoring of ergonomics · Limb tracking · Mental and physical workload

T. Römer (✉) · C. Stockinger · L. Bier
Institute of Ergonomics and Human Factors (IAD) TU Darmstadt,
Otto-Berndt-Straße 2, 64287 Darmstadt, Germany
e-mail: t.roemer@iad.tu-darmstadt.de

C. Stockinger
e-mail: c.stockinger@iad.tu-darmstadt.de

L. Bier
e-mail: l.bier@iad.tu-darmstadt.de

M. Soares et al. (eds.), *Advances in Ergonomics Modeling, Usability & Special Populations*, Advances in Intelligent Systems and Computing 486,
DOI 10.1007/978-3-319-41685-4_1

1 Introduction

Today, work life is subject to crucial changes. Not only for manual labor, but also for office jobs. Manufacturing companies are confronted with various emerging challenges. While the international competition rises, the market demands for faster innovation cycles at lower product prices and therefore shorter production times with less failure rates. Moreover, customers ask for more individualization options for their products. These demands require more flexible production processes and individual assembly up to batch size 1. The currently discussed approaches to master these challenges might be summed up within the forth industrial revolution, also referred to as Industry 4.0. The term has its origin in Germany. A detailed overview of this topic can be found in the works of Spath [1] or Botthof and Hartmann [2]. A short overview is available from Brettel et al. [3]. The basic idea is to integrate modern IT and communication technologies into production processes and combine them with recent innovations within assembly technology. The long term vision is, that all participants of the production process—humans, machines and products—are connected with each other with machines that use different identification methods and sensors to detect the status of products and even workers, to be able to flexibly adapt to a given situation. Therefore, the amount of human-machine cooperation in assembly processes will further increase. The focus of most of the present developments in this field lies on the machine perspective. Still, humans will have an important part within these processes, since they will still be in charge of controlling these systems of ever more complexity and make crucial decisions on a daily basis. This leads to increasing demands towards the employees, not on the side of manual labor but also on the side of mental workload when more and more information of increasing complexity has to be processed by the employee in a decreasing amount of time. Different studies show that the mental workload in work life is significantly increasing [4] and so are the numbers of mentally-related absence days, which applies especially to office jobs [5].

The Institute of Ergonomics and Human Factors at TU Darmstadt (IAD) is part of the project SmartF-IT [6], which deals with the challenges but also the chances of Industry 4.0. One of the goals is to develop concepts for cyber-physical support solutions that actively provide a benefit for participants within the assembly process.

The IAD develops these solutions by using the user centered design process (UCDP) according to DIN EN ISO 9241-210 [6] in order to achieve a high user friendliness and therefore a high acceptance of the solution. Possible results are support solutions on different levels.

On the organizational side the challenge is, that important information for leading positions about the assembly process is not available bundled, in real time and location-independent. A possible solution is a digital application on a mobile device that automatically collects all relevant information, notifies about human and machine failures, enables direct communication and recommends possible solutions which concept was developed earlier by IAD [7].

On the ergonomic level, the high degree of adaptivity and sensor equipment planned within Industry 4.0 offers chances to detect individual ergonomic aspects of the employees in order to automatically adapt their workplaces to them where possible. Another possibility is to use available sensors to detect and report ergonomic malpractice of the individual employee and show possible improvements. A field study and interviews conducted in the course of this project have shown that many assembly workers are not aware of the ergonomic aspects of their work. This is mainly due to the fact that they have no references about how ergonomic postures and limb movements look like and which ones are ergonomically not recommended. Also, the threshold when a certain movement leaves the recommended area is not known. Instead, most workers follow motion sequences that they are familiar with because they seem to be comfortable or effective. Some of these motions might not be favorable, but workers will not necessarily notice that, unless the motion immediately leads to pain or discomfort. Instead, the motion might have a negative long-term effect if repeated regularly. But if a long-term effect occurs, it is too late to intervene and the worker cannot relate it to the actions that have caused it. Several publications show, that work-related musculoskeletal issues are a common problem in the industry [8, 9]. But not only assembly work is related to health issues. Office jobs also have physical risks, due to wrong body or limb positions, especially concerning neck, back and wrists. More problems are bad lighting and insufficient movement. On the other side, a rapidly rising factor are issues related to mental overload. The increase of information in mass and complexity can lead to mental stress and ultimately to physical issues like heart attacks or mental issues like burnout [10].

In order to avoid these harmful states at work, the employees have to be notified about them. One possibility to do so is to track their ergonomic situation. There are already methods that allow ergonomic monitoring at work. However, these solutions are either always only snapshots, very complex, very expensive and or disturb the employees at work. Also, they are not designed to give direct feedback to the employees. To show a possible solution in the sense of an early indicator, this paper presents the user centered design and evaluation of a support solution, that gives employees direct feedback about the ergonomic quality of their actions during their workdays. This is done by using the built in sensors of everyday-life technology like smartphones, smartwatches or activity trackers to monitor different parameters of ergonomics at work, like limb positions, heart rate or environmental factors such as lighting.

2 Methodology

The goal of the presented design was to provide a solution to be used directly and actively by the employees in order to improve their working conditions based on their specific working environment and requirements. Therefore it was self-evident that the UCDP provided a suitable method for the development because it integrates

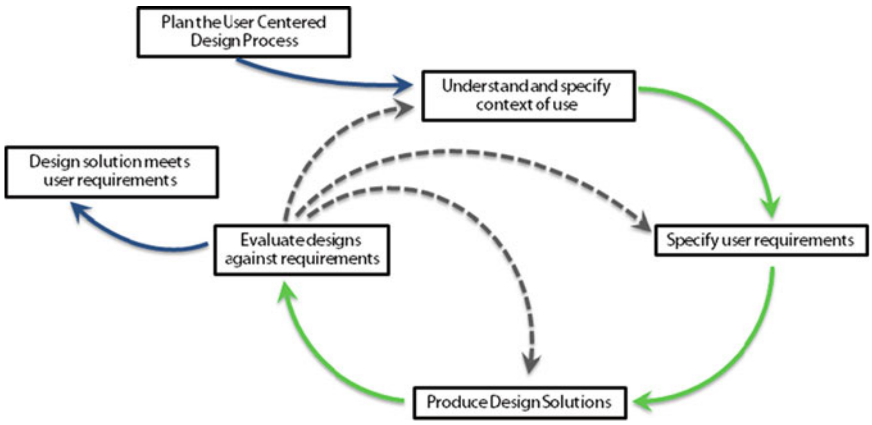


Fig. 1 The user centered design process according to DIN EN ISO 9241-210 [8]

the user perspective continuously from the beginning of the development. After the planning phase, the UCDP consists of the 4 main steps: understand and specify context of use, specify user requirements, produce solutions to meet user requirements, evaluate solutions against requirements. All these steps involve user participation or observation. This ensures that the requirements of the future users are incorporated in the design process from the beginning, in order to achieve solutions that feature a high usability and acceptance. The whole process is an iterative one, making it possible to jump back to any prior step as required to revise or complement the solution until it meets the user requirements. Figure 1 shows the UCDP according to DIN EN ISO 9241-210 [11].

The following sub-chapters explain how the four main steps of the UCDP are conducted to design the desired support solution for workers in assembly processes.

2.1 Context of Use

For the aspect of physical labor, the context of use may be deducted from the framework conditions given within the Project SmartF-IT. That includes cooperation with a large scale enterprise, which operates large assembly areas. In these areas a lot of assembly steps are performed manually by workers in cooperation with machines and tools of various types at the respective assembly workplaces. The workers receive a basic training according to the specific assembly task they have to perform which usually does not include information about ergonomic aspects of their work. The workers then perform the task more or less individually under the given boundary conditions. The topic of ergonomics is organized decentralized, so the focus on ergonomics varies significantly from plant to plant. Some plants temporarily employ a physiotherapist to teach workers ergonomic improvements in their motions and to teach team-leaders exercises that they can perform with their workers to prevent work related overstrain. However, such ergonomic support might not be offered at other plants. In any case, the workers themselves have only very limited options to proactively take part in the question of how to organize their work ergonomically—apart from handing in suggestions for the continuous improvement process. In addition, most workers do not know about the necessity of ergonomic behavior at work or the possible risks of its absence. If they do, they do not necessarily know which motions are ergonomically recommended and which are not.

Some plants have their workplaces assessed by standardized methods to categorize them in different levels, based on the strain on the whole body. This enables a comparison between different workplaces which can be of help for the assignment of workers to workplaces. Team leaders for example can decide after what amount of time workers should rotate and where to. But since the assessment is always a full body assessment, it does not show the strain on specific limbs, which limits the significance of the method. Different workplaces on hydraulic presses for example are all rated with high strain which makes a rotation between them look useless, but there are differences in the details concerning strain on the respective limbs. If they were detected, a rotation might look useful again.

For office work, the context of use is usually more simple, because workplaces there are very similar and there is rarely a risk of physical overload. Mental overload plays a far more important role. Still physical conditions can occur because employees do not alter between sitting and standing positions and lack enough movement in general. Also bad lighting and noise can be additional stress factors.

2.2 User Requirements

The user requirements can be deducted mainly from the context of use. The requirements can be separated in two parts. Part one is to make the employees aware of ergonomics during work. Part two is to give recommendations in case the worker does not work ergonomically or if the workplace does not allow to work ergonomically. A third part could be how to use statistics of the collected data to initiate long-term improvements.

For the first part, the support solution should be able to give the employees feedback about the ergonomic quality of their actions during work. This feedback should be given in real time and should differentiate between specific ergonomic parameters in order to enable the worker to directly relate it to the situation where it occurred. This requires real time tracking of the respective parameters. Since assembly work usually requires flexibility and precision of the workers, the devices used for tracking must not significantly harm these requirements. Also, most employees work under a certain time-pressure, so the feedback should be presented clearly so that the user can intuitively understand it and does not need to spend extra time on it. In addition, the user has to be notified in an appropriate way, for example by vibration, if sounds were either too quit or undesirable.

For the second part, suitable counter measures have to be found and implemented into the concept. Again, these recommendations should be easy to understand and easy to put into practice.

2.3 Design Solution

Based on the above requirements, a first design draft for a possible app on a mobile device was created in the form of a digital interactive prototype. This prototype showed the basic functionality of the proposed solution and thus served as a basis for discussion during the evaluations. The physical presence of a prototypical design facilitates the integration of the users, as they may comment on specific elements rather than to refer to a conceptual design, which is only described virtually and therefore interpreted differently by each person. In a second stage, the evaluated prototype was used to program an actual app. This app was then evaluated again.

The concept for tracking the motions of the different limbs is based on the use of sensors available in everyday life technology like smartphones, smartwatches and activity trackers. This has several advantages. First, it should lead to a high user acceptance, since the employees already know the utilized technology. Second, the devices are comparatively small and the most users wear them anyway. So the employees do not necessarily need to put on new devices and should not be significantly restricted in their movements.

2.4 Evaluation

Within the UCDP, evaluation has an important part. Every evaluation bears the chance to unveil flaws and show room for improvement in order to make the solution more user-friendly. The solution presented in this paper is based on a first digital prototype, which itself had four major evaluations with rising complexity. While the first two evaluations were conducted inhouse at IAD with random participants and usability experts from IAD to find a first suitable version and evaluate the optical and functional design of the concept, the third evaluation featured feedback from experts of the cooperating enterprise in order to evaluate the concept and the prototype through the enterprise perspective. The fourth evaluation then took the concept to the actual plant to evaluate it with workers. This lead to the conclusion, that for permanent tracking, the sensors had to be light and wearable without a strap or band. The prototype itself was rated as clear and intuitive.

This first prototype was then used to program an actual app, working with real data. This app was constantly evaluated during development on a bi-weekly basis and in addition was evaluated during two major evaluation sessions with possible future users. The feedback given to the app was much different and more critic in details than the one to the prior prototype, because people were doing the evaluation with different expectations now, knowing it is supposed to be a real working app and not a mockup anymore.

3 Results

Result of all the evaluations is a first version of an app that works with actual real-time data to give direct ergonomic feedback to employees during their work day. This app does not feature all the parameters that the interactive prototype featured, yet. But the control logic and the framework is already at a good stage and more features can be added at a later point.

In the current status of the app, an android-wear based smartwatch on the wrist and an Android smartphone in the pocket are combined to have different sensors available. This system might later be enhanced with several small activity trackers in the form of a clip mounted on different body positions to track several limb movements of the user.

The main screen (Fig. 2) of the app shows an overview over several ergonomic parameters which might be selected by personal preference. The view can be changed between the displayed grid view or an optional list view. If the number of parameters to be displayed exceed the screen size, the user can swipe down to see the other parameters. It is planned but not yet implemented that the parameters are arranged automatically based on the frequency of the occurrence of limit exceedances of the respective parameter. Parameters can be added to or removed from the main screen via the menu that can be accessed on the top left corner.

Figure 2 shows the three parameters that are already implemented: The heart rate, the number of steps per day and the position of the upper limbs. In future versions, more parameters are planned to be available, as well as a full body assessment. Each Parameter shows two values. For the heart rate, the current rate as well as the mean value of the rate is displayed. The steps indicator shows the already taken steps and the corresponding percentage of the daily goal. The upper limbs indicator shows the current position of the limbs as well as the percentage of how long unhealthy positions were taken so far. If the respective value exceed a recommended threshold, the indicator turns red to warn the user. Depending on personal preferences, an additional notification can be given through vibration or

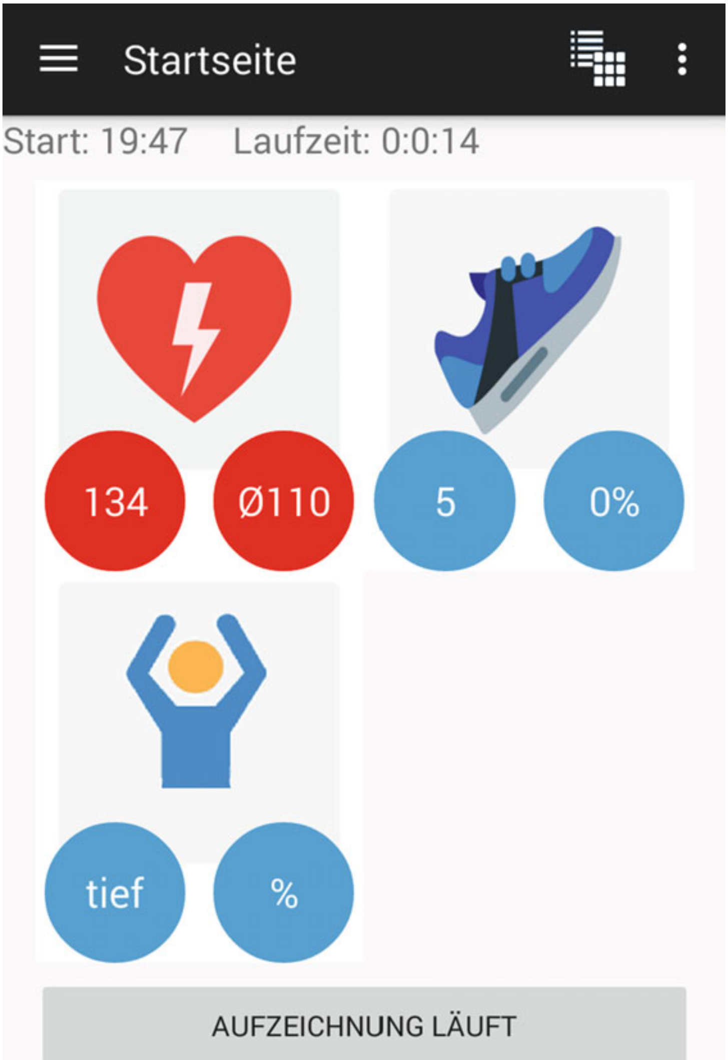


Fig. 2 Main screen of the app

sound of the devices used. The thresholds are calculated individually for each user, depending on his personal data like body height, weight and age.

If a threshold is exceeded, the display changes to a full screen view of the affected parameter to give the worker detailed information. Figure 3 shows the full screen view of the upper limbs indicator. After some seconds, the view changes back to the main screen. In a later version, the full screen view is supposed to show recommended measures like compensatory exercises or short breaks.

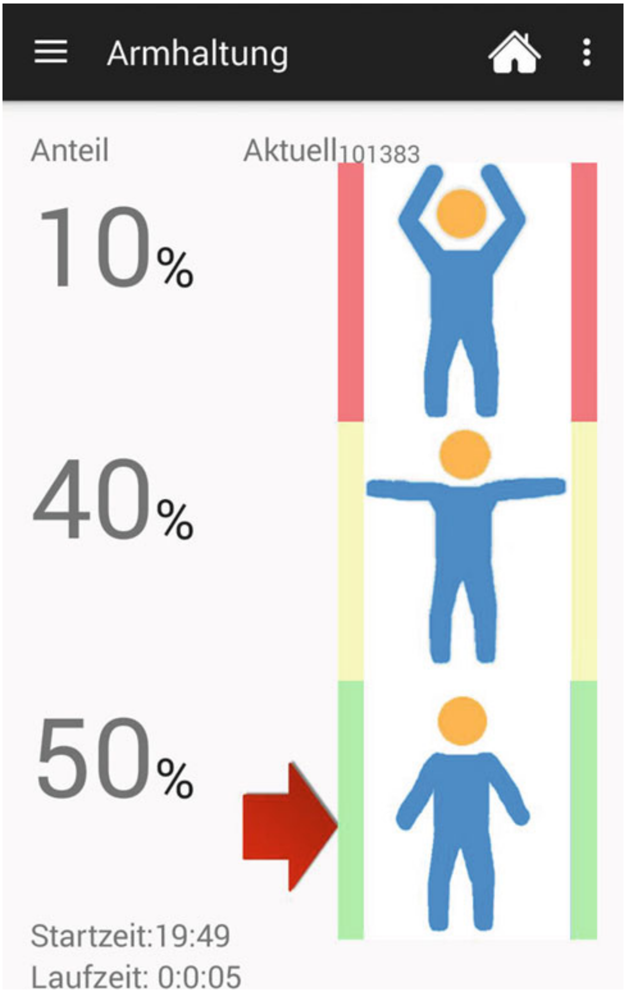


Fig. 3 Full screen view of the back parameter

4 Discussion

The presented solution yields possible benefits on different levels. The most obvious benefit is that employees become more aware of ergonomics at work—especially about which actions are ergonomically recommended and which ones are not. This can lead to a more ergonomic sensible behavior at work and may reduce work-related injuries and illness. An earlier study reported that from 110 interviewed workers, 85 % experienced work-related symptoms, 50 % had persistent work-related problems, but still less than 5 % of them had officially reported their problems because of fear of negative consequences [12]. The advantage of tracking parameters in real-time is that the workers can relate the feedback directly to their actual work instead of having to transfer theoretical, universal and abstract recommendations. This enables them to directly identify the problem themselves and autonomously work on improving it. Furthermore it is a possibility to rise the transparency of specific workplaces. If there is a workplace connected with prevalent ergonomic malpractice, direct feedback provided by the app can improve the communication between employees how to handle the work station ergonomically successful or it can initiate a discussion what to improve at the specific position. This improved transparency is especially an issue for office jobs, where detrimental factors are often not that evident, e.g. stress and mental workload. Here, a constantly raised heart rate, tracked be the app could for instance indicate a high mental workload connected with a job or specific tasks.

Sometimes specific workplaces demand specific actions that are not favorable. In these cases, the solution can still be of help by recommending compensatory exercises, workplace rotation or additional breaks.

A possible negative effect of using the app on such workplaces can be that employees might become scared or reluctant to work at this place in case they permanently get the feedback that this workplace leads to ergonomically recommended actions. In this case, the team leaders should communicate openly with their employees how to interpret the given information and set it into the right context. The availability of the data generated by the app for team leaders and supervisors could be a negative effect as well. Workers could feel strongly controlled, if supervisors have the possibility to analyze the data for every individual worker. This could eventually again rise stress and mental workload. It illustrates once more the need for an open, fair and result oriented communication culture within the company to benefit perfectly from the app.

Team leaders themselves are another group that may benefit from this solution. If data privacy regulations allow them to view the data of their employees, they could decide individually and precisely for each employee when he or she should change his working place and whereto in order to reduce the strain. If team leaders spot employees that have a very high rate of ergonomic malpractice they might initiate a training course in ergonomics for them. But even if team leaders only get anonymous data about the workplaces and not the single workers, they may use this quantified information to improve the workplaces on a long term perspective. Here, statistic data that may be accessed for a daily, weekly, monthly or yearly overview can be used to keep track of positive or negative effects of certain measures on a workplace.

5 Conclusion

The feedback from the many evaluations conducted within the UCDP, have shown that the presented app represents a suitable support solution for different employees and their leaders. It gives the users direct feedback and can help to improve their ergonomics at work. The utilization of the UCDP thereby has helped to reach a high user-friendliness and acceptance through many iterations based on direct user feedback. Yet, at this point the presented solution is only available as an early version of an app. The next step would be to enhance the app by more features and do more user tests and evaluations under real circumstances over a longer period of time to validate the app data and further improve the solution.

Another important point that has to be considered is the question about data privacy. This topic should be discussed by the responsible persons in the responsible councils and boards. General decisions and regulations should be made as soon as possible since it also affects other developments in the course of industry 4.0 and modern work life, especially the development of apps that rely on this data. Many developments also outside the project SmartF-IT show that apps are an important topic of industry 4.0 [13] and modern work life [14] in general.

With the ongoing progress of industry 4.0, more and more parts and participants of the production process will be digitalized and connected [15], making it possible to use even more data to integrate into the ergonomic feedback app.

References

1. Spath, D., Ganschar, O., Gerlach, S., Hämmerle, M., Krause, T., Schlund, S. (ed.): Produktionsarbeit der Zukunft—Industrie 4.0. Fraunhofer Verlag, Suttgart (2013)
2. Botthof, A., Hartmann, E.A.: Zukunft der Arbeit in Industrie 4.0. Springer Vieweg, Wiesbaden (2015)
3. Brettel, M., Friedrichsen, N., Keller, M., Rosenberg, M.: How virtualization, decentralization and network building change the manufacturing landscape: an industry 4.0 perspective. Int. J. Mech. Aerosp. Ind. Mechatron. Eng. **8**, 37–44 (2014)
4. German Confederation of Trade Unions (DGB): http://index-gute-arbeit.dgb.de/veroeffentlichungen/jahresreports/++co++83f44c88-9428-11e5-8b1e-52540023ef1a. Accessed Mar 2015
5. DAK-Gesundheit: http://www.dak.de/dak/download/Vollstaendiger_bundes-weiter_Gesundheitsreport_2015-1585948.pdf. Accessed Mar 2015
6. German Research Center for Artificial Intelligence (DFKI). http://www.smartf-it-projekt.de/?lang=en. Accessed Mar 2015
7. Römer, T., Wagner, T., Bruder, R.: Nutzergerechte Entwicklung einer mobilen, digitalen Unterstützungslösung in der Montage. In: 61. Kongress der Gesellschaft für Arbeitswissenschaft, Gesellschaft für Arbeitswissenschaft (2015)
8. Bernard, B.P., Putz-Anderson, V., et al.: A critical review of epidemiologic evidence for work-related musculoskeletal disorders of the neck, upper-extremity, and low-back. Technical Report, National Institute for Occupational Safety and Health (1997)
9. Armstrong, T.J., Buckle, P., Fine, L.J., Hagberg, M., Jonsson, B., Kilbom, A., Kuorinka, I.A., Silverstein, B.A., Sjogaard, G., Viikari-Juntura, E.R.: A conceptual model for work-related neck and upper-limb musculoskeletal disorders. Scand. J. Work Environ. Health **19**(2), 73–84 (1993)
10. Grifka, J., Tingart, M., Hofbauer, R., Peters, T.: Der Bürobildschirmarbeitsplatz aus orthopädisch-arbeitsmedizinischer Sicht. Der Orthopäde **31**, 1015–1022 (2002)

11. ISO DIS 9241-210:2010: Ergonomics of Human System Interaction—Part 210: Human-centered Design for Interactive Systems. International Standardization Organization (2011)
12. Pransky, G., Snyder, T., Dembe, A., Himmelstein, J.: Under-reporting of work-related disorders in the workplace: a case study and review of the literature. Ergonomics **42**(1), 171–182 (1999)
13. Gorecky, D., Schmitt, M., Loskyll, M., Zuhlke, D.: Human-machine-interaction in the industry 4.0 era. In: 12th IEEE International Conference on Industrial Informatics (INDIN), pp. 289–294. IEEE Press, New York (2014)
14. Roth, A.: Einführung und Umsetzung von Industrie 4.0. Springer, Berlin (2016)
15. Lucke, D., Constantinescu, C., Westkämper, E.: Smart factory-a step towards the next generation of manufacturing. In: Manufacturing Systems and Technologies for the New Frontier, pp. 115–118. Springer, London (2008)

Application Development for Gathering "Inexperienced UX" Data for Planning Next-Generation Products

Tomohiro Mori and Miwa Nakanishi

Abstract User experience (UX) is a concept that represents the psychological values regarding products. UX can be categorized into two types: one that a user has experienced (experienced UX) and another that a user has not experienced (inexperienced UX). In this study, we gathered experienced UX data and established a method to apply this data to next-generation product ideas. Additionally, an application was developed to gather inexperienced UX data and apply this data to the product design process. The goal was to establish a method to generate ideas for next-generation products in anticipation of the medium- and long-term future.

Keywords User experience · Product design · Cars

1 Introduction

Nowadays, cars are required not only for their functional values but also for their psychological values, such as providing pleasure. The focus is on the concept of user experience (UX). UX is defined as a user's experience that generates emotions, especially positive emotions, experienced during his/her interaction with a product [1, 2]. UX is generated by the actual users and not by the product providers; therefore, it is important for the product providers to gather UX data.

UX can be divided into two types: one that a user has experienced (experienced UX) and another that a user has not experienced (inexperienced UX).

In the case of inexperienced UX, the potential experiences and emotions that even the user is unaware of need to be extracted.

T. Mori (✉) · M. Nakanishi
Graduate School of Science and Technology,
Keio University, Yokohama, Japan
e-mail: t_mori@a7.keio.jp

M. Nakanishi
e-mail: miwa_nakanishi@ae.keio.ac.jp

M. Soares et al. (eds.), *Advances in Ergonomics Modeling, Usability & Special Populations*, Advances in Intelligent Systems and Computing 486,
DOI 10.1007/978-3-319-41685-4_2

In this study, data on the positive experiences of users were gathered using a smartphone application and a method to apply data to next-generation product ideas was established [3]. In collaboration with a car parts manufacturer, an experiment was conducted wherein designers generated ideas using the gathered past UX data. We found that this method produces ideas that often could not be imagined by designers and is effective for planning products that met the actual and potential needs of users. However, we also found that planning future products that users had not yet experienced was difficult.

In this study, an application was developed to gather users' desires (i.e., inexperienced UX) and apply them to the product design process. The goal was to establish a method for generating ideas for next-generation models in anticipation of the medium- and long-term future.

2 Existing Method for Gathering User Experience

This section deals with two existing methods, namely, persona and ethnography.

Persona is a method where product providers hypothesize the desired experiences by defining a specific profile of target users [4]. Ethnography is a method that explores and records user behavior during their participation in fieldwork in some group or society [5].

A drawback of Persona is that product providers are not necessarily able to extract the UX that users essentially desire because the person who defines the profile is not a user but a product provider.

In the case of Ethnography, product providers can extract the essential UX from users; however, it is an experienced UX. Thus, this method is not able to extract a potential inexperienced UX. Additionally, it is a time consuming to do fieldwork on multifarious users.

Two difficulties are experienced in the existing methods: (1) extracting a potential inexperienced UX and (2) gathering a sufficient amount of UX data. Therefore, the development of an application was undertaken to meet the following two requirements to address the abovementioned difficulties.

3 Requirements and Definition of the Application

3.1 Embodiment of Requirements

First, we focus on determining a method to extract a potential inexperienced UX.

In a study that analyzed the UX in housework and cooking [6], the drawing method [7] was adopted to express the desired experiences. The drawing method does not require difficult technology, and it is possible to convey complex ideas using a simple drawing [8]. Tanaka (2012) conducted a survey that required participants to reply to their desired images by drawing. Consequently, it became possible to express the desired ideas without an explanation. Therefore, the drawing method was adopted in this study.

Second, we focus on determining a method to gather a sufficient amount of UX data. It was challenging to gather large amounts of data because there are time and travel restrictions in completing multiple paper-based surveys. Hence, to reduce the time and travel restrictions, it was decided to gather data using a smartphone application.

Drawing illustrations on a smartphone is comparatively harder than doing it on paper. In a study of activation of drawing expression [9], it was shown that the external environments activate the drawing expression, e.g., a paper with an outline activates the drawing expression but not a blank paper.

Consequently, it was established that a creative activity is promoted by giving clues. Therefore, a way was adopted to let users generate ideas by looking at illustrations that are given to them as clues.

Taking the abovementioned findings into account, the following requirements of the application were determined:

- Gathering sufficient amount of data using a smartphone application
- Enable users to generate ideas by looking at illustrations that are given to them as clues
- Enable users to post their desires for the future as an "inexperienced UX" for various car-related situations

Purpose of Developing the Application

Applications that conduct surveys are not permitted to be distributed via the online application stores; therefore, a different purpose for developing the application was required.

Additionally, because users are usually unwilling to reply to traditional surveys, gathering large amounts of data would not be possible.

For these reasons, an application was developed where users can generate ideas with enjoyment.

The main requirement of the application is to enable users to generate ideas by looking at the illustrations that are given to them as clues. This is similar to "Ohgiri," a traditional Japanese game wherein players provide funny answers to questions on a given theme. Therefore, the application was developed as an "Ohgiri" game.

Additionally, to let users create ideas in an enjoyable way, functions that allow users to browse other users' answers were incorporated.

3.2 Experimental Determination of the Details of Giving Situations

A paper-based questionnaire was conducted to determine the details of giving situations.

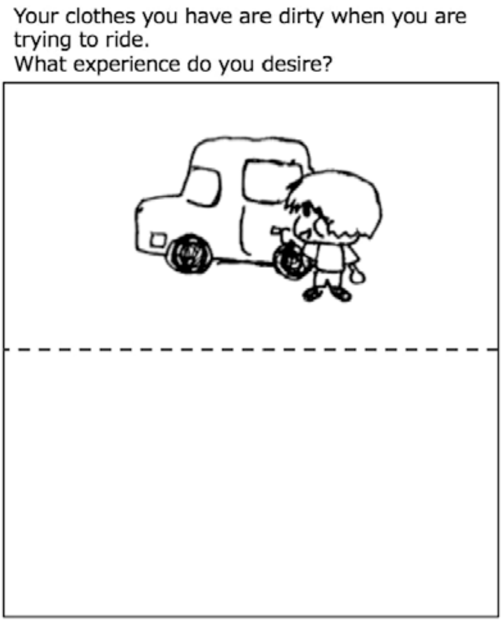
Method. Six participants, who were men and women in their 20s, were divided into two groups for the experiment. They replied with their future desires by looking at car-related illustrations. The participants in group A and B were asked to express their desires by looking at illustrations with detailed and rough descriptions of the situations, respectively. Two situations were given to each of the participants, and they were allowed to respond with multiple answers. Figures 1 and 2 show the questionnaire forms of group A, and Figs. 3 and 4 show those of group B.

Results. The following two points were examined in this study: (1) whether it is easy to generate ideas and (2) whether the generated ideas are correctly related to cars.

Assessment of (1) was done by comparing the number of ideas generated by each group. The total number of the ideas by group A was 14 and by group B was 6. Because the number of generated ideas by group A was more than that by group B, it was deduced that the conditions of group A made it easier to generate ideas.

Point (2) was examined by comparing the number of car-related ideas generated by each group. The total number of car-related ideas generated by group A was 14 and that by group B was 4. Hence, it was deduced that the conditions of group A made it easier to generate car-related ideas.

Fig. 1 Questionnaire forms of group A(1)



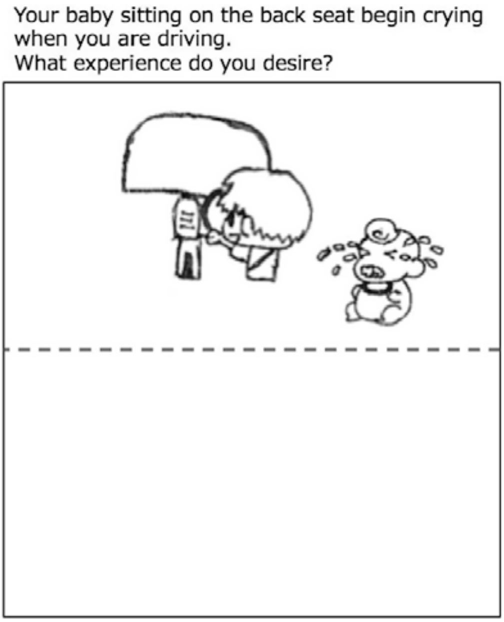


Fig. 2 Questionnaire forms of group A(2)

	details
Who	
Where	
When	When you are trying to ride
What	
How	

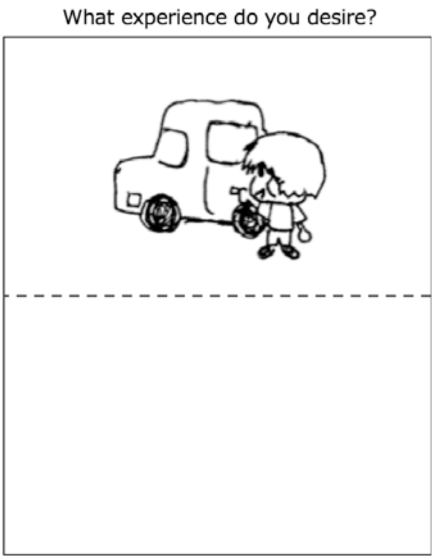
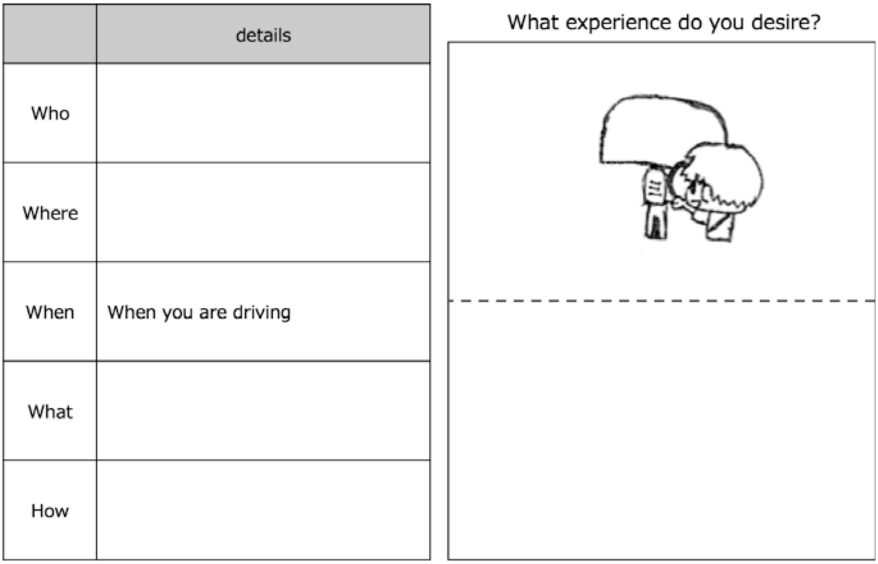


Fig. 3 Questionnaire forms of group B(1)



	details
Who	
Where	
When	When you are driving
What	
How	

What experience do you desire?

Fig. 4 Questionnaire forms of group B(2)

These results provided evidence that the conditions for group A (giving illustrations with a detailed description of the situations) were suitable for both of the examined points. Therefore, an application was developed for this method that lets users generate ideas by looking at the illustrations and provides clues that give a detailed description of the situations.

3.3 *Implementation of the Application*

Figure 5 shows a flowchart of the screen transitions. Figures 6, 7, 8, 9, 10 and 11 show various screen shots of the application.

The screen transitions occur between the three tabbed pages, namely, the Browsing Tab, Posting Tab, and My Page Tab.

All of the user's posts are listed on the My Page Tab, which contains a link to the Caution Page.

All situations are listed on the Posting Tab, where each situation links to the Posting Page. An illustration and a detailed description related to the chosen situation are displayed on the Posting Page. Users can post their future desires for a given situation.

All situations are also listed on Browsing Tab, where each situation links to the Browsing Page. Posts from all users related to the chosen situation are listed on this page.

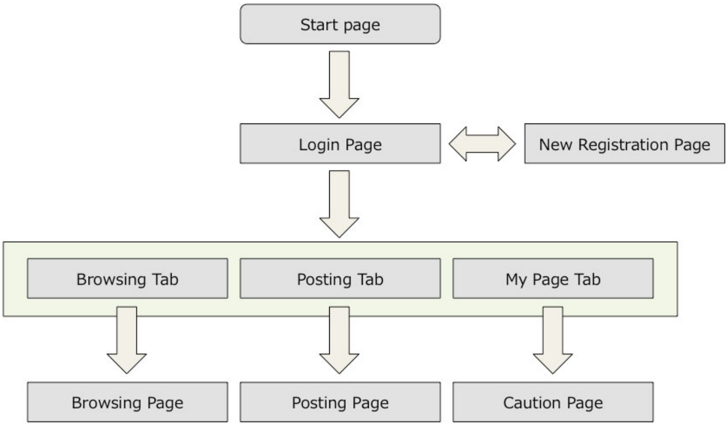


Fig. 5 Flowchart of the screen transitions

Fig. 6 Start page

Fig. 7 Browsing tab

Fig. 8 Posting tab

Fig. 9 My page tab

Fig. 10 Posting page

Fig. 11 Browsing page

3.4 *Operational Status*

The current status of the study is as follows:

- The developed application is available on the App Store (Application name: Car-giri).
- The total number of users is 22 (average age: 25.1 years old).
- The total number of posts is 147 (from December 15, 2015 to February 5, 2016)
- Ethics committee approval (No. 28-44; Faculty of Science and Technology, Keio University) was obtained.

Examples of posts are shown below.

Balloon of parking. Air bag cushions swell when the car is about to crash into something.
BGM understanding the situation. BGM that is appropriate for the mood in the car is played automatically.
Resort during a traffic jam. People on this car can savor the feelings of the resort by changed sound, smell and landscape when they are bored during a traffic jam.
Talking car. This car says "Have a nice day! Do your best again today!" when we closed the door.

3.5 *Problems and Developments*

Two new problems were identified while users operated the application. The first problem was the briefness of the description used as clues for illustrations. As a countermeasure, application of a method that uses illustrations as clues is proposed. Hazard prediction training covers topics regarding the prevention of human errors [10]. In this training, the clue illustrations are used to imagine the possible states

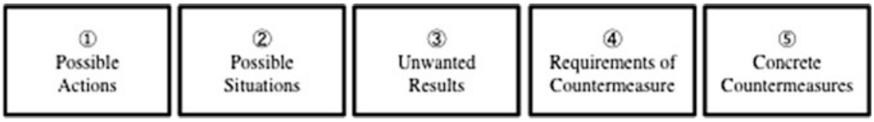


Fig. 12 The flow of illustrations analysis of hazard prediction training

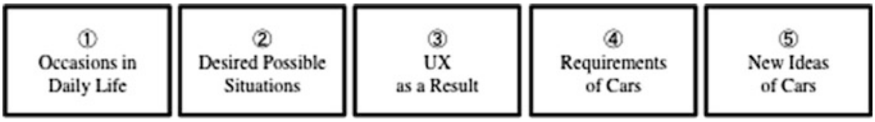


Fig. 13 The flow of gathering inexperienced UX

and objects in a specific situation. Hence, it can be said that effectiveness of clues for generating ideas is high. Application of the illustrations analysis method of the hazard prediction training is cited as a recommendation in this study.

The second problem was that the application was unable to gather many experiences. A fewer number of psychological values (desired experiences for the future) were gathered compared with that of desired functions. As a countermeasure, application of the flow of illustrations analysis of the hazard prediction training is proposed. Consequently, not only desired functions but also desired psychological values can be gathered. Figure 12 shows the flow of illustrations analysis of the hazard prediction training. Figure 13 shows the flow of gathering inexperienced UX.

In Fig. 13, "(4) Requirements of Cars" and "(5) New Ideas of Cars" are the parts that were gathered by the application. It can be considered that "(1) Occasions in Daily Life" is the part where illustrations were given. Therefore, the application has to be improved to gather information on "(2) Desired Possible Situations" and "(3) UX as a Result."

4 Conclusion

This study attempted to establish a method to gather inexperienced UX data for the interaction between users and cars with the aim of applying them to the product design process. Specifically, the requirements for gathering inexperienced UX were defined by extracting problems from existing methods and conducting an experiment. Consequently, a smartphone application was developed where users generate ideas by looking at illustrations and a detailed description of the situations that were given as clues; this approach gathered data from 147 posts.

However, two problems were identified. One is the briefness of the description used as clues for illustrations. The other is the inability of the application to gather sufficient data. Further development of the application is required.

Acknowledgments We wish to thank Tsuneyuki Yamamoto and Naoki Kamiya from TOKAI RIKA CO., LTD. for advice on experimental design.

References

1. Hassenzahl, M.: User experience (UX): towards an experiential perspective on product quality. In: Proceedings of the 20th International Conference of the Association Francophone d'Interaction Homme-Machine. ACM (2008)
2. Watson, D.L., Tellegen, A.: Towards a consensual structure of mood. Psychol. Bull. **9**(8), 219–235 (1985)
3. Hama, D., Nakanishi, M.: UX-based design-planning process: a practical study for car accessories. Graduation thesis, Keio University (2014)
4. Cooper, A.: The Inmates Are Running the Asylum. SAMS (1999)
5. Van Maanen, J.: Takes of the Field. University of Chicago Press (1988)
6. Tanaka, Y.: Analysis of user experience in housework and cooking—development of design process methodologies for home appliances. Graduation thesis, Keio University (2012)
7. Kearney, K.S., Adrienne, E.H.: Drawing out emotions: the use of participant-produced drawings in qualitative inquiry. Qual. Res. **4**(3), 361–382 (2004)
8. Fleury, A.: Drawing and acting as user experience research tools. In: Proceedings of the 10th Asia Pacific Conference on Computer human interaction. ACM (2012)
9. Oda, K., Takahashi, T.: A study of the art curriculum in preschool that aims at comprehensive art education. Hum. Dev. Res. **26**, 39–50 (2012)
10. Japan International Center for Occupational Safety and Health: Retrieved from http://www.jniosh.go.jp/icpro/jicosh-old/index.html. Accessed 18 Jan 2016

Study on Bottom Somatotypes Characteristics and Differences of Female Youths from Liaoning Province and Guangdong Province in China

Jing Zhou and Xiaoping Hu

Abstract This paper mainly studies the bottom somatotype characteristics and differences of the young female in the southern and northern regions of China. During the experiment, we selected the young female aging from 20 to 29 years old as the research object. In order to ensure the accuracy of the data in the experimental process, garment-specialty students are required to take the measurements of body parts including height, abdomen, waist, hip, leg length, thigh, shank and ankle girth. During the investigation, we have collected 102 young women's lower-body figure data. Half of the measured young female are from Liaoning province in northern China, while the other half are from Guangdong Province in southern China. Based on the SPSS statistical software, the bottom somatotype characteristics and differences of the young female in two regions were statistically described. In the study of this paper, the difference between the hip and the waist is the main basis for the study of features and differences of the body size. This study can not only provide some reference for bottom somatotype garment size of the young female in the north and the South respectively, but also the certain data support for detailed classification of garment size.

Keywords Bottom somatotype characteristic · Somatotype classification · Youth female · Waist-hip difference

1 Introduction

At this stage, the trunk of the human body is the main research part of garment, but for the detailed study and classification about bottom somatotype characteristics can seldom be seen. According to the men, women and children, garment sizes are classified. But for the young female in different regions, there is no specific criteria

J. Zhou · X. Hu (✉)
School of Design, Guangzhou Higher Education Mega Center, South China University of Technology, Panyu District, Guangzhou 510006, People's Republic of China
e-mail: huxp@scut.edu.cn

M. Soares et al. (eds.), *Advances in Ergonomics Modeling, Usability & Special Populations*, Advances in Intelligent Systems and Computing 486,
DOI 10.1007/978-3-319-41685-4_3

for the classification, which leads to the current apparel market, and apparel product difficult to meet the demand of sizes of the young female in different regions. So it is very necessary to study the characteristics and differences of the bottom body of the young women in the north and south of China. Due to the influence of various factors, such as genetic heredity, physical acquired growth, living habits, eating habits and daily work and so on, make people's bottom somatotype in the north and South regions more obviously different. Good apparel needs to fit for somatotype size and the study of somatotype in different periods, different regions and different ages is the basic requirements of improving the design of clothing structure. So based on this problem, research on somatotype and garment size for women in different areas is imperative.

2 Domestic and International Garment-Size Classification Status

2.1 Chinese Garment-Size Classification

2.1.1 Garment-Size Classification Is Simple

In China, there are only four classification in women's apparel sizes and styles. And the garment standard classification does not take into account the age and geographical differences. This makes a lot of customers in the market hard to buy the suitable size. However, in many developed countries, the standard classification of their garment-sizes is very detailed. For example, the relatively developed clothing industry in Japan, garment standard is divided into seven categories, including Y type, YA type, A type, AB type, B type, BE type and E type. At the same time, according to their ages, they also put women's sizes into three, including girl body shape, young female body shape and common female body shape. Thus, garment classification in Japan is quite detailed.

2.1.2 Out-of-Date Size Data

In the late 80s of the 20th century, Chinese conducted a large-scale basic human data collection activity of garment-size standard which the GB/T1335-1991 garment-size standard is written based on. Later the standard was published in 1997 and 2008, and the 2008 version has been used so far. But standard apparel sizes of the two versions were slight adjustment based on the 1991 version based and did not update the basic data of human body. With the improvement of living conditions, Chinese people's body shape, compared, is to a large extend different from that of the 20 years ago, so the current garment standard is too old, and lack of reference value for garment company to produce the needed clothing.

2.2 Classification Methods in Domestic and Overseas

The classification of the somatotype provides an important reference value for the development of garment standards. Many countries have different methods and standards of somatotype classification to make the garment standards. As a whole, there are several ways. The first way is to divide the circumference by the difference between chest and waist, waist and hip, chest and hip. The second way is to divide the circumference of height, weight, age and chest circumference. The third way is based on the various kinds of indexes of the somatotype, such as the proportion of body and chest, chest circumference and waist circumference. The fourth way use the classification of index according to the circumference of chest, waist and hip. The last one is the classification of different somatotype types according to the cluster analysis of the body data.

In China, the somatotype is mainly based on the difference between chest and waist. However, with the changes of the young female somatotype, the difference between chest and waist can not represent all the body shapes. So in this study, we chose the young female from 20 to 29 years in the south and north to carry out physical data measurement and scientific analysis.

3 Experiment

3.1 Experiment Area

The study selected Liaoning province in north China and Guangdong province in south China as experiment areas, which are far away from each other. These two provinces have large population. And there are many differences between these two areas. Non-local students are not selected in this experiment.

3.2 Experimental Objects

In the experiment, we use the random sampling method to collect data. The collected sample included 108 young women aging from 20 to 29 and respectively from Liaoning province and Guangdong province. Data were collected from January 30, 2016 to January 10, 2016.

3.3 The Measurement Parts

In order to integrate the experimental goals with the requirements, we choose the most representative 10 basic body parts for the data measurement in bottom clothing production. The measured body parts include height, waist circumference, hip circumference, thigh circumference, Shank circumference, leg length and ankle circumference. These measurements cover the main and key parts of somatotype and can meet the relevant data analysis of various somatotypes.

3.4 The Measurement Methods and Tools

Because of the limited condition, the traditional manual measurement method was used in the experiment. In order to ensure the accuracy of data measurement, we have arranged for a fixed professionals to carry out data measurement. In the whole process of the measurement, the person being measured is wearing a close-fitting and light underwear. The body is relaxed with natural standing, the line of sight looking directly, the arm maintaining the loose state. Finally, the band tape is applied to measure data.

4 Data Analysis

4.1 Data Pre-processing

In the experimental measurements, we measured 108 young women. In order to ensure the accuracy and reliability of the measurement data, we first have a data pre-processing of the measured data. After checking the measurement data, some unreasonable data was eliminated. Finally, there are 102 groups of effective data left with 94 % effective rate.

4.2 Methods Analysis

In the process of analysis, we use SPSS software to conduct the data analysis of the mean value and the standard deviation. Then the independent samples T test was carried out to summarize the characteristics of human body in the north and south areas. Then the differences of the young women's body size in the northern and southern regions were compared.

4.3 Data Analysis

After the collection and analysis of measurement data, we can know respectively the data distribution of north and the south leg length, waist circumference and hip circumference. In the chart, the vertical coordinates represent the quantity, and the horizontal coordinates represent the circumference or the length of the measured parts. From Charts 1, 2 and 3, we can know that waist circumference of young women in northern is mainly concentrated from 68 to 75 cm; the hip circumference of northern young female is mainly from 82 to 101 cm; the leg length of young female in northern mainly concentrated from 87 to 98 cm, accounting for 76.5 %. From Charts 4, 5 and 6, we can know the young women's waist in southern ares is mainly distributed from 63 to 70 cm with the percentage of 74.5 %. The young female hip circumference is mainly distributed from 86 to 95 cm with the percentage of 76.5 %. Female youth of the southern leg length is mainly distributed from 87 cm to 98 cm with the percentage of 76.5 %. Compared with the young women's circumference of chest, waist and hip in southern parts, we can found that waist and hip circumference of female youth in northern areas were larger, but the leg length are very similar.

4.4 Data Dispersion Analysis

Standard deviation can reflect the dispersion trend. When the standard deviation is large, the degree of dispersion is larger. In contrast, when the standard deviation is smaller, the degree of dispersion is more concentrated. From Table 1, we can see the 3 larger standard deviation items are: northern young female waist circumference with 7.522 cm standard deviation; abdominal circumference of young female in the north is 8.069 cm and the standard deviation of hip circumference is 6.744 cm. This shows that the circumference of waist, abdomen and hip of northern young female are quite different.

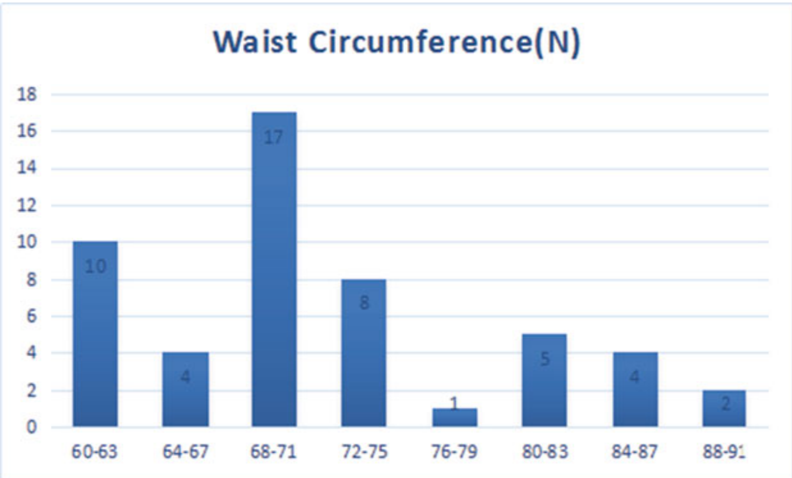


Chart. 1 The distribution of waist circumference (N)

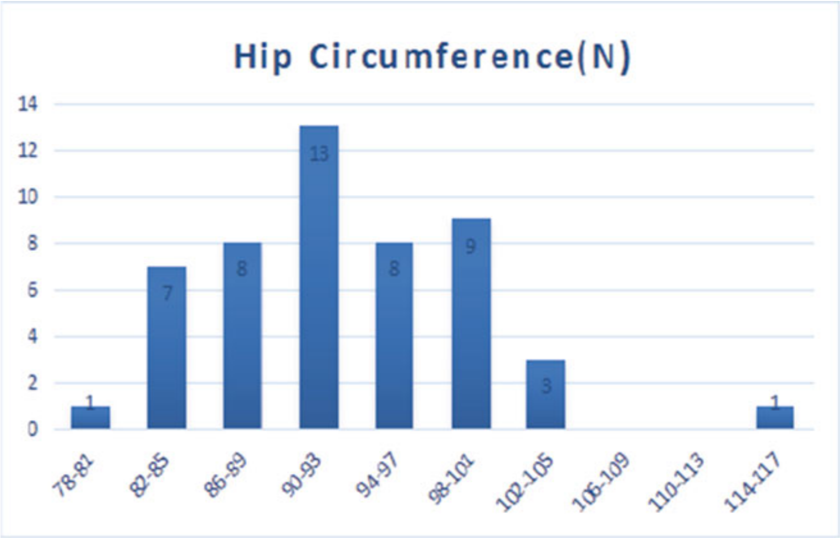


Chart. 2 The distribution of hip circumference (N)

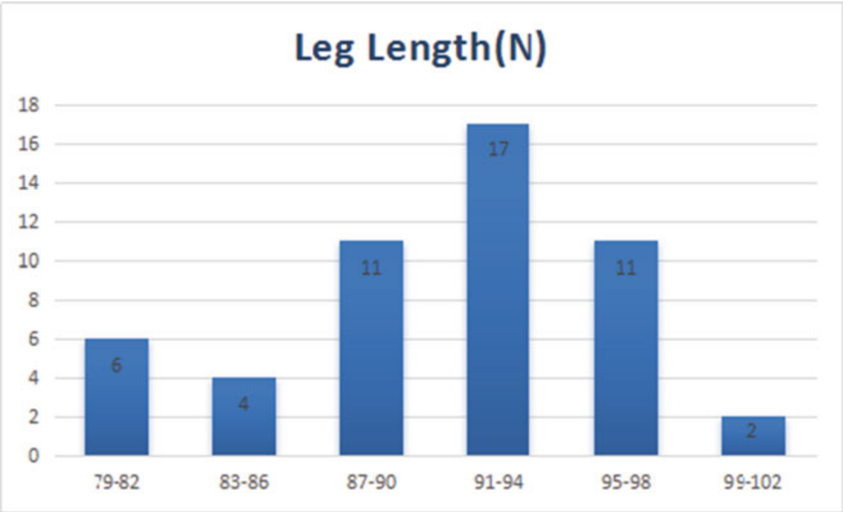


Chart. 3 The distribution of leg length (N)

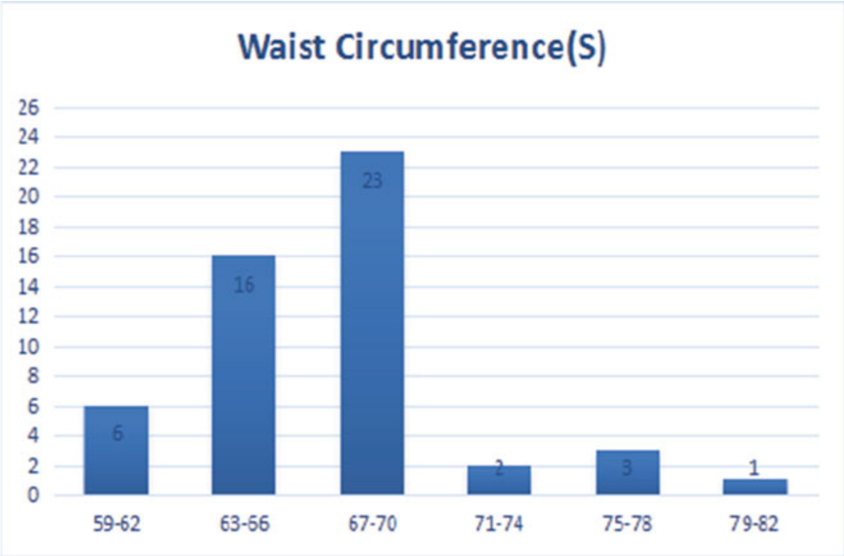


Chart. 4 The distribution of waist circumference (S)

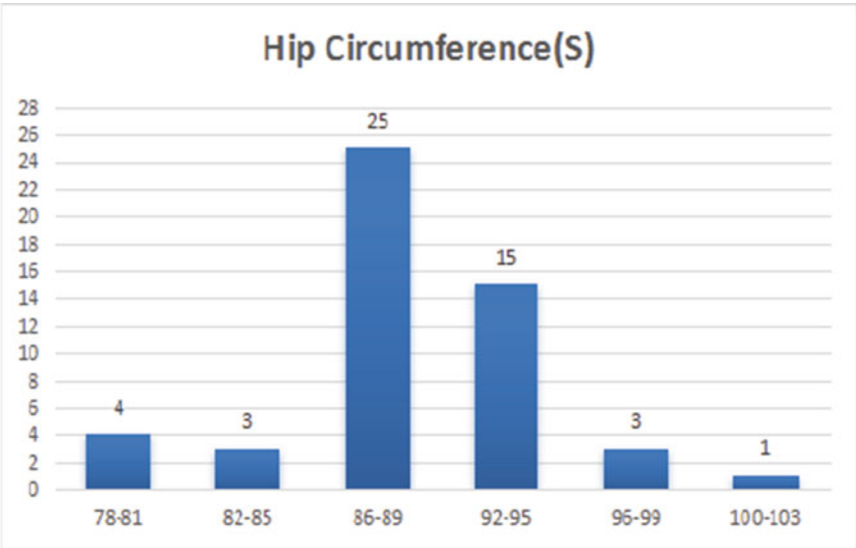


Chart. 5 The distribution of hip circumference (S)

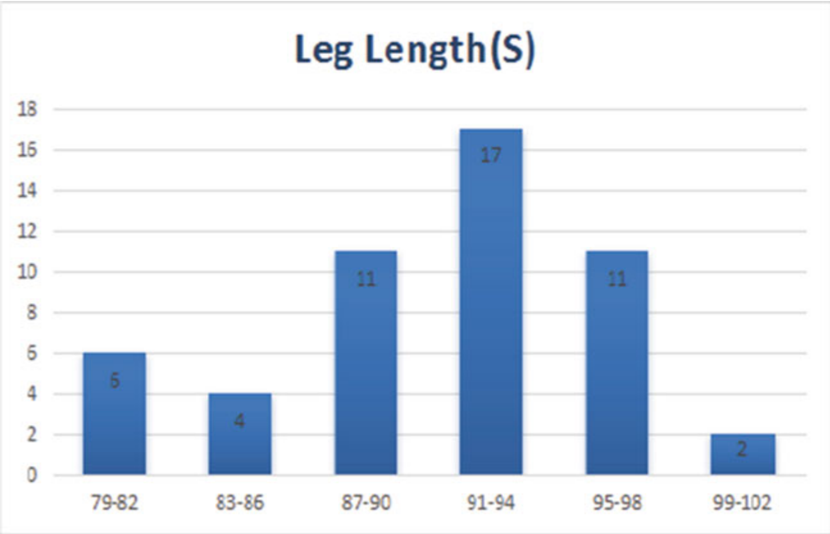


Chart. 6 The distribution of leg length (S)

Table 1 Circumference of waist, abdomen, hip, thigh, shank and ankle of northern young female

	Native place	N	Mean	Std. deviation	Std. error mean
Height (cm)	N	51	165.38	4.560	0.632
	S	51	159.92	4.685	0.656
Leg length (cm)	N	51	90.63	5.111	0.709
	S	51	86.38	4.884	0.684
Waist circumference (cm)	N	51	71.51	7.522	1.043
	S	51	67.17	4.256	0.596
Abdomen circumference (cm)	N	51	77.06	8.069	1.119
	S	51	72.24	5.237	0.733
Hip circumference (cm)	N	51	92.83	6.744	0.935
	S	51	90.23	3.867	0.541
Thigh circumference (cm)	N	51	53.13	5.484	0.761
	S	51	50.32	4.293	0.601
Shank circumference (cm)	N	51	35.19	3.913	0.543
	S	51	33.51	2.719	0.381
Ankle circumference (cm)	N	51	21.58	1.819	0.252
	S	51	20.22	1.361	0.191

4.5 Independent-Samples T Test

In order to make the body shape classification more clearly reflect the overall shape characteristics, we need to combine several different investigation and analysis methods. In this study, we use SPSS software independent samples T test to analyze.

If the F detection of Sig value in the chart is larger than 0.05, that is the number of homogeneous variance, and then from looking at the first line of the equal assumed variance, the significance level of T detection can be observed. If the Sig value (bilateral) is larger than 0.05, there is no difference between the two. Conversely, if the Sig (bilateral) value is less than 0.05, then from looking at the second line of the in-equal variance, the significant level of T detection can be observed. If the Sig (bilateral) value is larger than 0.05, there is no difference between the two. On the contrary, if the Sig (bilateral) value is less than 0.05, there are differences between the two.

From the independent sample T test and Table 2, we can learn:

(1) There was a significant difference in the height of the female youth between the north and the south.
(2) There was a significant difference in waist circumference between the northern and southern regions.
(3) There was significant difference in abdomen circumference between north and south.
(4) There is significant difference between the hip circumference of northern female youths and the hip circumference of southern female youths.
(5) There was a significant difference in the legs length between the female youth in the north and the south.
(6) There was a significant difference in the thigh circumference between the female youth in the northern and southern regions.
(7) There was no significant difference in Shank circumference between the northern and southern parts of the female youth.
(8) There was a significant difference between the ankle circumference of the female youth in the northern and southern regions.

5 Conclusion

After analyzing the characteristics of female youth in the north and South regions, we found that there was a significant difference in bottom somatotype between the female youth in the southern and northern regions. Most of the female youth's bottom somatotype characteristics in the northern part is larger than that of the southern female youth. This research can provide a certain reference for designers and clothing enterprises in designing South and North women's dress. In addition,

Table 2 Independent-samples T test

		Levene's test for equality of variances		T-test for equality of means						
		F	Sig.	T	df	Sig. (2-tailed)	Mean difference	Std. error difference	95 % Confidence interval of the difference	
									Lower	Upper
Height (cm)	Equal variances assumed	0.054	0.818	5.997	101	0.000	5.463	0.911	3.656	7.270
	Equal variances not assumed			5.995	100.779	0.000	5.463	0.911	3.655	7.271
Leg length (cm)	Equal variances assumed	0.089	0.766	4.201	99	0.000	4.218	1.004	2.226	6.210
	Equal variances not assumed			4.199	98.324	0.000	4.218	1.004	2.224	6.211
Waist circumference (cm)	Equal variances assumed	12.827	0.001	3.597	101	0.001	4.343	1.207	1.948	6.738
	Equal variances not assumed			3.615	80.936	0.001	4.343	1.201	1.953	6.733
Abdomen circumference (cm)	Equal variances assumed	13.726	0.000	3.590	101	0.001	4.822	1.343	2.158	7.487
	Equal variances not assumed			3.605	87.708	0.001	4.822	1.338	2.164	7.481
Hip circumference (cm)	Equal variances assumed	10.892	0.001	2.395	101	0.018	2.601	1.086	0.447	4.756
	Equal variances not assumed			2.407	81.575	0.018	2.601	1.081	0.452	4.751

(continued)

Table 2 (continued)

		Levene's test for equality of variances		T-test for equality of means						
		F	Sig.	T	df	Sig. (2-tailed)	Mean difference	Std. error difference	95 % Confidence interval of the difference	
									Lower	Upper
Thigh circumference (cm)	Equal variances assumed	2.118	0.149	2.885	99	0.005	2.856	0.990	0.892	4.821
	Equal variances not assumed			2.877	91.952	0.005	2.856	0.993	0.885	4.828
Shank circumference (cm)	Equal variances assumed	2.443	0.121	−0.724	99	0.471	−4.635	6.403	−17.340	8.071
	Equal variances not assumed			−0.731	50.783	0.468	−4.635	6.341	−17.365	8.096
Ankle circumference (cm)	Equal variances assumed	0.089	0.766	4.201	99	0.000	4.218	1.004	2.226	6.210
	Equal variances not assumed			4.199	98.324	0.000	4.218	1.004	2.224	6.211

this research has certain practical value, which is beneficial to the development of related products. But at the same time, some relevant data also needs to pay more attention to in order to continue to deepen and expand the research on different regions of bottom somatotype and size classification.

Analysis of Back Forces While Sitting Down, Seated, and Rising from a Stationary Chair in Subjects Weighing 136–186 kg

Lingling Hu, Onder Tor, Jilei Zhang, Bob Tackett and Xiaohong Yu

Abstract Limited research was found related to the study of back forces on chairs sat on by people who weighed over 136 kg. The Business Institutional Furniture Manufactures Association needs force data for development of performance test standards to test chairs for users who weigh up to 181 kg. 20 participants who weighed from 136 to 186 kg completed six tasks on an instrumented chair in the sequence of sitting down, remaining seated, and rising. Effects of sitting motion, armrest use, and seat cushion thickness on back forces and centre-of-force were investigated. Results indicated hard sitting down yielded the highest back force of 34.7 % in terms of participants' body weights. Armrest use and cushion thickness affected back forces of normal sitting down, but not of rising, hard sitting down, and remaining seated.

Keywords Back force · Body weight · Centre of force · Stationary chair bariatric

1 Introduction

Modern furniture design should incorporate the full range of body sizes [1]. World Health Organisation (WHO) globally estimated that more than 1.9 billion adults who were 18 years of age and older were overweight of which over 600 million were obese in the world [2]. In the case of the United States (US), the population of

L. Hu (✉) · X. Yu
Department of Industrial Design,
Zhejiang A & F University, Hangzhou, China
e-mail: radiant00@163.com

O. Tor
Department of Forest Industrial Engineering,
Faculty of Forestry, Kastamonu University, Kastamonu, Turkey

J. Zhang · B. Tackett
Department of Sustainable Bioproducts,
Mississippi State University, Starkville, USA

M. Soares et al. (eds.), *Advances in Ergonomics Modeling, Usability & Special Populations*, Advances in Intelligent Systems and Computing 486,
DOI 10.1007/978-3-319-41685-4_4

overweight or obese people have gradually increased from 13 % in 1962 (National Health Interview Survey, 2008) [3] to almost 70 % in 2013 (Organisation for Economic Co-operation and Development (OECD). OECD has also estimated that the percentage of overweight or obese U.S. citizens will be 75 % of U.S. population by 2020 [4]. Safety and durability are considered the most important basic concerns for seat design used by people weighing over 136 kg because the largest portion of the body weight transfers to the chair components such as the seat pan, backrest, armrests, and legs. These all components may negatively affect the overall performance of the chair, and even cause the chair to fail [5]. However, traditionally, the load design of chair, including backrest, evolved from experience gained by trial and error [6].

The role of a backrest is allowing the sitter to lean beyond the vertical position. A chair with a reclining backrest can reduce the sitting forces impacted on the seat pan by transferring a significant amount of body weight to floor via the backrest among different daily activities [7–9]. Additionally, the backrest is considered to contribute more to the overall sitting comfort than the seat pan [10], through maintaining lumbar lordosis, relaxing spine musculature, and mitigating stress on spinal and other paraspinal structures [7, 9, 11]. When sitting with no back support, the low back disc pressures are 140 % of standing disc pressure [12]. Back pain and stress, which are associated with obesity, contribute to the decline of workforce productivity and efficiency [13]. As the population's weight has increased, chair designer has responded with more support features that allow a broader range of people to sit safely and comfortably. Thus, the backrest of a chair has become a focal point in seating and chair design [14].

There is no reported back force-testing standard for people weighing over 136 kg. In general, the back load design pertaining to safety and durability in United States follows the performance-testing standard ANSI/BIFMA X5.4-2012 established by the Business Institute of Furniture Manufacture Association (BIFMA), and the GSA loading spec standard. The BIFMA standard defines the load magnitude of 90 kg for vertical static strength test with loading device attached to the unit so that the force is applied vertically through an area defined by the thickness of the backrest by 406 $\pm$ 13 mm along the width of the backrest, centered on the apparent weakest point at the top of the backrest for the 95th percentile male weight of 115 kg based on the CAESAR anthropometric database [15].

This paper reports the results of back forces from a study carried out at Mississippi State University with the hypotheses of considering the forces in terms of the percentage of body weight of human subjects on the seat, arms, and back of a stationary chair during sitting down and rising by human subjects whose weights range from 136 to 186 kg will be different from previous studies with human subjects who weigh significantly less than 136 kg. Therefore, the specific objectives of this back force study were to (1) obtain magnitudes of back forces and their centre locations, and (2) evaluate effects of sitting motion, armrest usage, and seat cushion thickness on back forces and their centre locations.

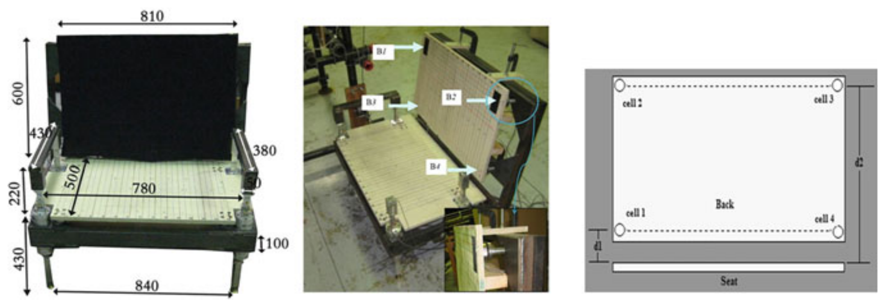
2 Methodology

2.1 *Participants*

Twenty participants (10 males and 10 females) were recruited from the local community, with average age (COV) of 39 years (33 %). Average (COV) weight, height, and BMI of participants were 162 kg (9 %), 1733 mm (4 %), and 54 kg/m^3 (10 %), respectively. Average (COV) popliteal height and buttock-popliteal length were 362 mm (16 %) and 542 mm (7 %), respectively. Average (COV) waist breadth, trunk height (Eye height sitting subtracting 430 mm/seat pan height, and trunk weight (45.2 % of BW) were 470 mm (8 %), 350 mm (11 %) and 73 kg (9 %), respectively. Detailed data about individual participants can be found in the report [16].

2.2 *Equipment*

A laboratory stationary chair was designed with legs, arms, and a backrest oriented 10° beyond vertical (Fig. 1a). Four load cells (PT Global LPX-250 button load cells with 250 kg loading capacity) were attached at the corners of the backrest as shown in Fig. 1b to measure and record back forces which are perpendicular to the backrest surface when the participants sit down, remaining seated, and rising. The dimensions of the chair were determined by getting an approximate average of the dimensions of chairs designed for larger people from four chair manufacturers. All load cells' and strain gauges' outputs used to determine forces were recorded using a National Instrument SCXI-1000, with two 1102B modules. All back force values are given in kilograms equivalent at normal gravity in order to be easily compared to body weight [17].



a) b) c)

Fig. 1 **a** Force measuring stationary chair with pertinent dimensions shown (unit: mm). **b** Load cells were attached to the backside of the back at the corners of the back area. Four load cells were named as B1 (*upper-right* load cell, with respect to sitter), B2 (*upper-left* load cell), B3 (*lower-right* load cell), B4 (*lower-left* load cell). **c** Determining the vertical location for the load on the back

2.3 Experimental Procedure

Anthropometric measurements of participants were conducted at the beginning, and participants were then instructed to finish six tasks in the following sequence: Task 1—sit down normally with two armrests used, then sit statically for three to five seconds without armrest, and follow by rising with two armrests used; Task 2—sit down normally with armrest use optional, then shift their body side-to-side as they normally would shift their weight, and follow by rising with armrest use optional; Task 3—sit down normally with armrest use optional, then stretch backward one time with hands up and behind head, and rise with one armrest used; Task 4—sit down hard with two armrests used, then sit statically for three to five seconds without armrest use, and rise with two armrests used; Task 5—sit down hard with armrest use optional, then shift body side-to-side, and follow by rising with armrest use optional; Task 6—sit down hard with armrest use optional, stretch backward one time with hands up and behind head, rise with one armrest. This regimen was first done to the seat with no cushion, and repeated with a 5-cm-thick cushion, and then a 10-cm-thick cushion, respectively. It took about 45 min to an hour for one participant to complete all 18 tasks (1, 2, 3, 4, 5, and 6) and cushion thicknesses (0, 5, 10 cm). Ethical approval was obtained from the Mississippi State University Institutional Review board and Human Research Protection Program, and written informed consent was obtained from all participants [17].

2.4 Analysis

The back force, F_B, is standardized to the percentage of body weight (W), $BW\%$, using the following expression [18].

$$BW\% = \frac{F_B}{W} \times 100 \tag{1}$$

The magnitude of a back force was the sum of four loading forces recorded through four load cells B_1, B_2, B_3, and B_4 (Fig. 1b) during the period of a participant sitting down, remaining seated, and rising.

The centre-of-force, COF, is defined as the distance from the surface of the seat to the horizontal line on the backrest as shown in Fig. 1c where the back and reaction forces on the backrest equilibrated during the sitting. By summing all moments in Fig. 2b, Eq. (2) for calculation of COF on the backrest can be obtained

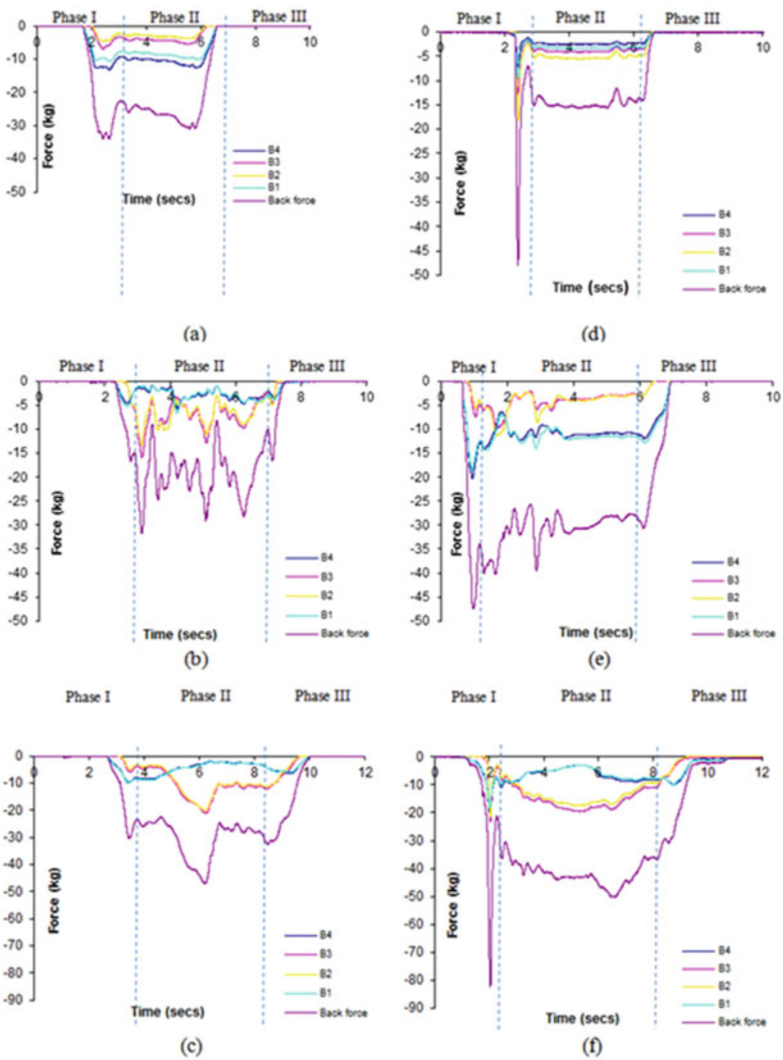


Fig. 2 Typical back force curves of six tasks; **a** Task 1, **b** Task 2, **c** Task 3, **d** Task 4, **e** Task 5, and **f** Task 6

$$\begin{aligned}
&\sum M_o = 0, \\
&R_3(d_2 - COF) + R_4(d_2 - COF) - R_1(COF - d_1) - R_2(COF - d_1) = 0 \\
&COF = \frac{(R_1 + R_2) \times d_1 + (R_3 + R_4) \times d_2}{R_1 + R_2 + R_3 + R_4}
\end{aligned} \tag{2}$$

where R_1, R_2, R_3, and R_4 are the reaction forces perpendicularly to the backrest surface, recorded by load cells B_1, B_2, B_3, and B_4 which are located at the four supporting corners of the backrest (Fig. 2a), respectively; d_1 is the distance between the centre line of load cells B_1, B_2, and the surface of the seat; and d_2 is the distance between the centre line of load cells B_3, B_4, and the surface of the seat.

For data statistical analyses, the Shapiro-Wilk (W) test (SAS Institute INC 1999) was performed first to check the normality of all data sets. The Shapiro-Wilk values were 0.912 (P value < 0.0001) and 0.988 (P value 0.06) for back force and COF data sets of normal sitting down and rising, 0.983 (P value 0.7885) and 0.953 for back force and COF data sets of hard sitting type I, and 0.990 (P value 0.335) and 0.985 (P value 0.08) for back force and COF data sets of being seated actions, respectively. These results indicated that all data sets were normally distributed. The general linear model of analysis of variance (ANOVA) procedure was performed on the unbalanced individual data points using SAS software (SAS Institute INC 1999) to analyse main effects and their interactions on the peak back force and COF value at the 5 % significance level [19]. If the interaction was analysed the protected least significant difference (LSD) multiple comparisons procedure at the 5 % significance level was performed to determine mean differences among different treatment combinations.

3 Results

Figure 2 shows typical back force-time curves that reflect different sitting behaviours of participants during the completion of the six asks in this study. For static seated situation (Fig. 2a, d), the higher peak back force between two tasks completed by the same participant was chosen to represent that person's back force. For shifting situation (Fig. 2b, e), some participants moved their bodies up and down vertically instead of shifting from side to side per instruction, therefore, their corresponding back forces were removed from the data set used for analyses. For the stretching event (Fig. 2c, f), the highest back force point was chosen between these two tasks.

The peak back force within each of the three phases for all recorded curves was identified and analysed through first obtaining the actual numbers of participants (Table 1) recorded for each experiment combination of cushion thickness by task by sitting down motion by phase by armrest use. For instance, to screen out lower BW% values of sitting forces from hard sitting down data for those participants who had sat down normally even though they were instructed to sit down hard, the average BW% value of peak sitting forces at phase I for all normal sitting down cases was calculated first, i.e., the BW% value was used as a baseline.

Tables 2 and 3 summarizes ANOVA results of peak back forces and COF values for three data groups of normal sitting down and rising, hard sitting down, and seated situations, respectively.

Table 1 Summary of mean peak back forces in terms of percentage of body weight and COF values for participants who completed phase I of normal sitting down and phase III of normal rising

Phase	Armrest use	Cushion thickness	Back force (%)			COF		
			Mean	Range	COV	Mean (mm)	Range (mm)	COV (%)
I	Two	None	27	14–51	41.3	313	239–419	15.4
		5 cm	22	11–35	35.6	277	195–344	17.5
		10 cm	22	3–40	42.3	274	131–489	29.6
	One	None	27	17–39	34.7	310	198–460	32.1
		5 cm	30	21–41	28.9	271	208–316	17.0
		10 cm	25	20–31	16.4	266	155–325	26.5
	Neither	None	30	17–43	30.5	327	221–409	18.9
		5 cm	30	19–43	31.2	339	270–479	16.8
		10 cm	21	15–31	21.6	341	228–448	20.0
III	Two	None	16	10–21	17.6	290	130–427	29.4
		5 cm	19	13–25	18.0	300	216–425	24.0
		10 cm	17	12–25	22.4	308	179–420	25.9
	One	None	18	14–22	15.0	360	288–399	10.0
		5 cm	21	15–34	26.1	356	224–447	18.9
		10 cm	20	15–24	13.7	372	262–468	16.1
	Neither	None	20	14–26	25.1	335	207–411	21.7
		5 cm	17	12–19	16.9	283	208–405	25.3
		10 cm	16	13–20	14.6	355	291–438	15.3

Table 2 Summary of the p-values from ANOVA analysis of back forces and COF for each of three data groups

Source	Data group					
	Normal sitting down and rising		Hard sitting down type I		Seated	
	Back force	COF	Back force	COF	Back force	COF
Motion	<0.0001	0.01			<0.0001	<0.0001
Arm	0.03	0.003	0.175	0.964		
Cushion	0.02	0.3	0.54	0.565	0.396	0.012
Motion ∗ Arm	0.29	0.003				
Arm ∗ Cushion	0.2	0.75	0.489	0.957		
Motion ∗ Cushion	0.09	0.23			0.323	0.793
Motion ∗ Arm ∗ Cushion	0.23	0.37				

Table 3 Summary of the p-values from ANOVA analysis of back forces and COF for each of three data groups

Source	Data group					
	Normal sitting down and rising		Hard sitting down		Seated	
	Back force	COF	Back force	COF	Back force	COF
Motion	<0.0001	0.01	0.665	0.07	<0.0001	<0.0001
Arm	0.03	0.003	0.176	0.641		
Cushion	0.02	0.3	0.105	0.52	0.396	0.012
Motion ∗ Arm	0.29	0.003	0.826	0.524		
Arm ∗ Cushion	0.2	0.75	0.492	0.331		
Motion ∗ Cushion	0.09	0.23	0.202	0.198	0.323	0.793
Motion ∗ Arm ∗ Cushion	0.23	0.37	0.629	0.244		

4 Discussion

4.1 Back Force

Sitting motion effect

For normal sitting down and rising situations, in general, normal sitting down yielded a higher peak back force than normal rising (Table 4). This is mainly because the sitting down process from standing to sitting had a higher potential energy converted to a higher impact load on the backrest when compared with going from a seated position to rising. Actually, recorded sitting force data [17] indicated that, in general, the back force impacted on the backrest reaches its peak right after the sitting force reaches its peak during normal sitting down (Fig. 2a), i.e. because of this delayed impact would be able to influence by sitting down motion. However, the back force reaches its peak ahead of the sitting force reaches its peak during normal rising (Fig. 2b). This difference was significant when the seat cushion thickness was less than 10 cm but where the two armrests used with 5-cm-thick seat cushion. This was because when 10-cm-thick seat cushion was used, the higher seat surface can increase participants' thigh angle from vertical and the larger thigh angle tends to shift more weight on the legs thereby less contact at the backrest, which reduced back forces [11, 20, 21].

Armrest usage effect

In general, armrest usage affects the peak back forces significantly for normal sitting down situations, while it has no influence on the peak back forces for normal rising and hard sitting down (Table 5). This is mainly because the back force impacted on the backrest reaches its peak around 2.0 s after the arm force reaches its peak during normal sitting down because of this delayed impact would be able to influence by armrest usage.

Table 4 Mean comparisons of back forces (%) and centre-of-force (COF) values of normal sitting down and rising for each factor of sitting motion within each combination of the other two factors of armrest use and cushion thickness

Armrest use	Cushion thickness (cm)	Motion	
		Normal sitting down	Normal rising
		Back force (%)	
Two	0	27.5 A	16.2 B
	5	21.5 A	18.7 A
	10	22.1 A	16.9 A
One	0	27.2 A	18.1 B
	5	29.8 A	21.0 B
	10	24.6 A	19.7 A
Neither	0	30.5 A	19.7 B
	5	29.5 A	16.6 B
	10	21.4 A	15.8 A
		COF (mm)	
Two	0	314 A	290 A
	5	277 A	300 A
	10	274 A	308 A
One	0	310 A	360 A
	5	271 B	356 A
	10	266 B	372 A
Neither	0	327 A	335 A
	5	339 A	283 A
	10	341 A	355 A

Table 5 Mean comparisons of back forces (%) and centre-of-force (COF) values of normal sitting down and rising for each factor of within each combination of armrest use the other two factors of sitting motion and cushion thickness

Motion	Cushion thickness (cm)	Armrest use		
		Two	One	Neither
		Back force (%)		
Normal sitting down	0	27.5 A	27.2 A	30.5 A
	5	21.5 B	29.8 A	29.5 A
	10	22.1 AB	24.6 A	21.4 B
Normal rising	0	16.2 A	18.1 A	19.7 A
	5	18.7 A	21.0 A	16.6 A
	10	16.9 A	19.6 A	15.8 A
		COF (mm)		
Normal sitting down	0	314 A	310 A	327 A
	5	277 B	271 B	339 A
	10	274 B	266 B	341 A
Normal rising	0	290 B	360 A	335 AB
	5	300 AB	356 A	283 B
	10	308 B	372 A	355 AB

Table 6 Mean comparisons of back forces (%) and centre-of-force (COF) values of normal sitting down and rising for each factor of within each combination of cushion thickness the other two factors of sitting motion and armrest use

Motion	Armrest use	Cushion thickness (cm)		
		0	5	10
		Back force (%)		
Normal sitting down	Two	27.5 A	21.5 B	22.1 B
	One	27.2 A	29.8 A	24.6 A
	Neither	30.5 A	29.5 A	21.4 B
Normal rising	Two	16.2 A	18.7 A	16.9 A
	One	18.1 A	21 A	19.6 A
	Neither	19.7 A	16.6 A	15.8 A
		COF (mm)		
Normal sitting down	Two	314 A	277 A	274 A
	One	310 A	271 A	266 A
	Neither	327 A	339 A	341 A
Normal rising	Two	290 A	300 A	308 A
	One	360 A	356 A	372 A
	Neither	335 AB	283 B	355 A

Cushion thickness effect

In general, seat cushion thickness has no influence on the peak back forces of normal rising, hard sitting down, and remaining seated, but normal sitting down. For normal sitting down, seat cushion thickness had significant influence when two armrests were used, and neither armrest was used, but one armrest was used. The mean comparisons (Table 6) indicated normal sitting down with two armrests when seat cushion used has a significantly lower back force than that of normal sitting down with two armrests when no seat cushion used.

Acknowledgments Special thanks are due to Leland Manufacturing of Leland, Mississippi, Tupelo Manufacturing Company of Tupelo, Mississippi, and to BIFMA, the Business + Institutional Furniture Manufactures Association, who each provided significant funds toward this research. Thanks are also due to John Norton of Herman Miller who provided assistance and equipment to the project. Appreciation is also extended to Dave Panning of BIFMA, and to the roundtable of furniture manufacturing professionals that he gathered to help the project along. Startup Fund for Distinguished Scholars from Zhejiang A & F University: 101/2034020080.

References

1. Kroemer, K.H.E., Kroemer, H.B., Kroemer-Elbert, K.E.: Ergonomics: How to Design for Ease and Efficiency. Prentice Hall, New York (2001)
2. World Health Organisation (WHO): Obesity and overweight. http://www.who.int/mediacentre/factsheets/fs311/en/ (2015)

3. National Institutes of Health (NIH): Clinical guidelines on the identification, evaluation and treatment of overweight and obesity in adults: the evidence report (Report No. 98-408). NIH, National Heart, Lung and Blood Institute. Nerhood, Bethesda, MD (1998)
4. Organisation of Economic Co-operation and Development (OECD): Obesity update. http://www.oecd.org/health/49716427.pdf (2012)
5. Cooper, R.A.: Rehabilitation Engineering Applied to Mobility and Manipulation (Applied to Mobility and Manipulation). Taylor & Francis, London (1995)
6. Eckelman, C.A.: Textbook of Product Engineering and Strength Design of Furniture. Purdue University, West Lafayette (2003)
7. Corlett, E.N., Eklund, J.A.E.: How does a backrest work? Appl. Ergonomics **15**, 111–114 (1984)
8. Huang, H.C., Yeh, C.H., Chen, C.M., Lin, Y.S., Chung, K.C.: Sliding and pressure evaluation on conventional and V-shaped seats of reclining wheelchairs for stroke patients with flaccid hemiplegia: a crossover trial. J. Neuroeng. Rehabil. **8**, 40 (2011)
9. Li, C.T., Chen, C.H., Chen, Y.N., Chang, C.H., Tsai, K.H.: Biomechanical evaluation of a navel wheelchair backrest for elderly people. Biomed. Eng. **2015**(14), 14 (2015)
10. Oudenhuijzen, A., Tan, K.: Quantifying the Comfortable Seat Developing Measureable Parameters Relating to Subjective Comfort. IBEC (1991)
11. Nag, P.K., Pal, S., Kotadiya, S.M., Nag, A., Gosai, K.: Human–seat interface analysis of upper and lower body weight distribution. Int. J. Ind. Ergon. **38**, 539–545 (2008)
12. Kroemer, K.H.E., Grandjean, E.: Fitting the Task to the Human: A Textbook of Occupational Ergonomics. CRC Press, Boca Raton (1997)
13. Perry, L.S.: Standing up, redesigning the workplace to address obesity. Prof. Saf. 77–84 (2012). www.asse.org
14. Steven, M.C., Peter, J.K.: Effects of backrest design on biomechanics and comfort during seated work. Appl. Ergon. **38**(2007), 755–764 (2006)
15. Business Institute of Furniture Manufacture Association (BIFMA): The performance-testing standard ANSI/BIFMA X5.4-2012 (2012)
16. Zhang, J., Tackett, B., Martin, B.: Measuring Humans for Heavy Duty Chair Testing and Design. BIFMA Report (2013)
17. Hu, L., Tackett, B., Tor, O., Zhang, J.: Analysis of sittin forces on stationary chairs for daily activities. Ergonomics (2015). doi:10.1080/00140139.2015.1080311
18. SAS Institute INC. SAS/STAT User's Guide, Version 8. Cary (1999)
19. Bush, T.R., Hubbard, R.P.: Support force measures of midsized men in seated positions. J. Biomech. Eng. 58–65 (2007)
20. Nawayseh, N., Griffin, M.J.: Tri-axial forces at the seat and backrest during whole-body vertical vibration. J. Sound Vib. **277**, 309–326 (2004)
21. Tarczay, A.: Study of distributed occupant-seat interactions as an objective measure of seating comfort. Master dissertation, Concordia University (2005)

User Participation in the Design of Cockpit Interfaces

Ulrika Ohlander, Jens Alfredson, Maria Riveiro and Göran Falkman

Abstract This paper investigates the nature of user participation in the process of designing fighter aircraft cockpits. The role of the users, i.e. pilots, in the design of cockpit interfaces is explored. We present the results of an on-line questionnaire with twelve designers of cockpit interfaces for fighter aircraft. The results show that the designers have highlighted the need for more opportunities to observe the pilots, and they wish to obtain more information and ideas from them. Moreover, a larger involvement from users as examiners and testers in the evaluation process was desirable. Access to users was considered unproblematic and the risk of misunderstandings was reported to be low. Moreover, the designers did not support the idea that users should design or take design decisions.

Keywords User participation · User involvement · Fighter aircraft

1 Introduction

The design of user interfaces for complex systems such as fighter aircraft is challenging in many ways [1]. This is both because of the complexity of the technical systems and the challenging scenarios the aircraft are to be used in [2]. Since the designers of fighter aircraft normally have little personal experience of the systems to be developed, the involvement of experienced users in the design process is a

U. Ohlander (✉) · J. Alfredson
Saab Aeronautics, Saab AB, Linköping, Sweden
e-mail: ulrika.ohlander@saabgroup.com

J. Alfredson
e-mail: jens.alfredson@saabgroup.com

U. Ohlander · M. Riveiro · G. Falkman
School of Informatics, University of Skövde, Skövde, Sweden
e-mail: maria.riveiro@his.se

G. Falkman
e-mail: goran.falkman@his.se

M. Soares et al. (eds.), *Advances in Ergonomics Modeling, Usability & Special Populations*, Advances in Intelligent Systems and Computing 486,
DOI 10.1007/978-3-319-41685-4_5

common and natural approach. This paper investigates and discusses how users can be involved and participate in the design process. The objective is to understand and describe the role of user representatives and how the designers work with them in the design process. How do the designers collect and consider user requirements and information about the users, the context and needs?

There are two main reasons to involve users in the design and development of information systems; morale and pragmatic. The morale calls for involving the people that actually will end up using the system in the creation of it. This view, based on the philosophy of neo-humanism is especially prevailing when designing for the community and the public user [3]. The opposite view, based on the pragmatic functionalism paradigm, prescribes to involve users in order to build better systems by understanding the user's needs and preferences [4]. The functionalist paradigm is the most prevailing, both in academia and among system developers [5]. To involve users in the design and development of interfaces for complex systems is a common approach, and the intention is to secure that user requirements are met and to create a usable system. However, even though the involvement of users in system design has been embraced by practitioners, there are mixed results concerning whether this makes the systems more successful [4, 6]. An exception are projects with high levels of task or system complexity, where user participation has been demonstrated to correlate with user satisfaction [7].

User involvement and user participation are two common labels for the involvement of users in system design. Sometimes they are used interchangeably, and sometimes they are claimed to be two different notions, where user participation stands for the users taking active part in development activities, and involvement refers to a psychological state, the user's belief that the system is important and relevant [6]. In this paper both terms are equally used for activities in direct contact with users during the design process. The development process contains several stages and the users may participate during different parts and in different activities.

Different philosophies and approaches have been offered through the years for the development of user interfaces in general, such as for example; participatory design, user centered design, user experience, effect mapping etcetera [8–10]. All these methods propose various ways of involving the users in the design process. User involvement can be beneficial, but there are also several challenges [11]. Examples of such challenges are; access to users, little consensus across users, users unaware of implementation constraints, and user′s lack of understanding the design process and of what developers need to know. Based on the general challenges identified by Kujala [11] and a literature review, this paper presents a survey in order to investigate the involvement of the user (pilot) in the design process of fighter aircraft. The results of the survey are presented and the specific issues for the domain are discussed and compared to practices from other areas.

In addition to the general challenges identified above the following issues that are domain specific need to be considered during the design process. All the design philosophies mentioned above stress the fact that access to users is central in the design process, and since fighter pilots are scarce this might be an issue in the domain. Moreover, fighter aircraft are usually acquired by governmental agencies and operated by air forces. Even though the purchasing organizations might have their own user representatives, they are not the ones that will use the systems in the end.

User interfaces are often tested and developed in prototyped environments and evaluated in simulators with different degrees of fidelity. This is the only feasible way of getting feedback during the development, since feedback from the end users in the target environment will come years later.

Due to the long development times for fighter aircraft there is also a need to predict future use of the system. The scenarios that are the base for the design are in many cases assumptions, and the difficulties to make correct forecasts are obvious. Technology is developing fast, and the aim for the design is often to be flexible and able to incorporate future upgrades and changes in technology.

Requirements on the user interfaces can also originate from several sources other than the users. Regulations and safety requirements are examples of requirements that must be incorporated in addition to the user's needs.

2 Method

In order to investigate the involvement of the fighter pilots in the process of designing interfaces, we decided to outline a questionnaire that inquire about the following issues: the designers' views on the user representatives, current and desirable roles of the pilots, important knowledge needed to carry out the designers job and sources of information.

The questionnaire was distributed by e-mail to 16 designers of user interfaces in fighter aircraft. 12 of the approached designers completed the questionnaire, which gave a response rate of 75 %. Of the respondents, 4 were female and 8 male. Their ages were between 29 and 51, with a mean of 39 years. The average time they have worked as HMI designers in this area was 7.7 years, ranging from 3 to 25 years. None of the respondents were pilots, nor military or private. The questionnaires were in Swedish.

3 Results

On the question "how many years of experience do you think is needed for someone to work as a designer", the answers ranged between 1 and 10 years, with 3.3 ($\sigma = 2.8$), years as a mean.

A number of questions were asked were the respondents should give their answer on a seven grade rating scale; the average and standard deviation values of their numerical answers are listed in Table 1.

Table 1 Questions and ratings

Question	Mean rate on 7 grade rating scale	σ
To what extent to you consider yourself to have enough knowledge about how pilots work?	4.8	0.8
To what extent do you think that the users you work with are representative for the end users?	5.2	1.5
To what extent do you find that there are several different opinions about the design among the users?	5.7	1.2
To what extent are you prevented from doing your work due to the availability of users?	3.3	1.4
To what extent do you think there is a risk of misunderstandings between designers and users?	3.3	1.3
How important do you think it is that the users know how to design?	5.0	1.9
How important are the following knowledge and competencies for you as a designer?		
General knowledge about tactical use of the aircraft systems	5.8	1.0
Operational performance of air missions	6.3	0.6
Sub-system knowledge, for example about the fuel system?	5.0	1.4
Methods for designing user interfaces	6.3	0.9
Knowledge about the avionics system (target system)	4.5	1.2
Programming skills	3.6	1.2
To what extent do you user the following as sources for your design?		
Requirements documentation	4.1	1.6
System descriptions	5.4	1.4
Style guide	5.6	1.5
Colleagues	6.5	0.9
Users	6.3	1.4

The respondents were also asked to select alternatives for different roles that users can have during the design. Several alternatives were possible. The results are listed in Table 2.

On the question "Who do you think should decide when there are different opinions about the design?" the majority answered either the specialized fellow engineer (5) or the chief engineer (4). Only two persons thought that it should either be the users or the designer.

Even though the sample is small with only 12 participants, some general remarks and observations can be made.

The designers thought that the users they work with are fairly representative for the whole community of end users. Moreover, the respondents did not consider access to users to be a significant problem, and they think they understand each other. Furthermore, the designers agree it is important that the pilots understand the design process.

Table 2 Different roles that designers think the users have today and should have in the design process

User Role	As is today	Desirable
Object for observation	6	10
Information provider	10	12
Contributor of ideas	9	11
Advisor	11	12
Examiner	9	11
Tester	9	10
Designer	3	2
Decision maker	5	3
Other*	0	1

The largest difference between actual and desired state has been underlined
*One respondent suggested that pilots give information about other aircraft they have flown

The designers answered that the pilots have and should have many different roles in the design process. It can be noted the designers wish to be able to observe pilots at work more and to get more information and ideas from them. To observe is the aspect that shows the largest difference on how it is now (6) and how they would like it to be (10). They also think that pilots should be more involved as examiners and testers. However, pilots should not be designers or decision-makers according to the majority of respondents.

Designers indicated that it might be a problem that the users often hold different opinions about the design. In these cases it is preferred if a senior chief engineer responsible for the project in question or a senior principal engineer takes the final decision.

Knowledge of the operational and tactical use of the plane is together with methods for design valued as the most important skills for the designers, while knowledge about the hardware, avionics, and programming is considered less important.

Colleagues and users are ranked as the best sources for design.

4 Discussion

Access to users is highlighted in the literature as a common problem [11], probably because the users are normally not found within the developing organization but have to be recruited from outside. Manufacturers of aircraft have test pilots within the company that take part in the design activities. This probably explains why the designers did not consider access to users to be a problem. However, when the highly skilled and specialized test pilots take part as user representatives there could be a risk that the design will be optimal for a highly skilled pilot, not the average user in the air force [12].

The pilots were considered representative of the end users. This is important since the end users normally are quite distant from the manufacturing company both in terms of geography and time. Fighter aircraft projects are usually long, and there can be a considerable amount of time between requirements capture and introduction of the new system to the end users.

The designers indicated they think it is important for the pilots to understand the design process. Support for this can be found in [13], this study stresses the importance of informed users. They need to understand when decisions will be made and the consequences of the decisions.

The designers selected several different roles that they thought the users should have. Different forms for how users can be involved in the design are possible; *informative, consultative* and *participative* [14]. The informative role was in the questionnaire covered by the roles *object for observation*, *information provider,* and *contributor of ideas*. The consultative form, for example users trying a prototype, is covered by the roles *advisor*, *examiner*, and *tester*. Finally, the roles *designer* and *decision maker* belong to the participatory form where users have more influence on the final product. The responses indicate that the designers would like the users to contribute more in the informative and consulting forms rather than the participative, where a decrease is desirable. In this area, as with many large and complex systems, the user is not the one that does the procurement, there are many actors involved in this process. Consequently, the designers will have to consider requirements and regulations from many other stakeholders. This could explain the designers' notion that the pilots should not be involved in the decision-making process. This may seem to contradict other findings, for example regarding agricultural decisions support systems, where it was concluded that user influence was positively related to system success [15]. User influence was in this context regarded as a more important construct than user participation or user involvement, stressing the importance of the impact of the user's opinions.

Regarding knowledge and skills of the designers, knowledge of the operational and tactical use of the plane was considered the most important. This is probably also the skills that are the most difficult to obtain. Methods for design, and programming skills are competencies the designers learn during their education, but the domain specific knowledge needs to be acquired on the job.

The designers ranked colleagues and users as the best sources for design. This probably connects to the need for domain specific knowledge. Because of the complexity of the fighter aircraft system, the designers need to discuss and consult with more senior colleagues and the users that are experts in the field. It can also be noted that several commented on the question about how many years of experience they thought is needed for a designer to work independently. The designers argued that due to the complexity of the systems it is not really appropriate for anyone to work on their own, only for small limited design tasks. The ability to cooperate interdisciplinary with users and other experts in the field was highlighted.

5 Conclusions and Future Work

In this paper, we have presented the results of an on-line questionnaire with twelve designers of pilot interfaces for fighter aircraft, in order to investigate the role of the user representatives in the design process.

In general, the designers do not feel that their work suffers from not having more access to the pilots, and that they think they understand each other. However, the designers indicated that there are user roles where they think pilots could contribute more. In particular, the designers have highlighted the need of more opportunities to observe the pilots, obtaining more information and ideas from them, and a larger involvement in the evaluation process as examiners and testers. On the other hand, the designers concluded that the pilots should not act as designers and decision makers, and that the chief engineer normally should take the decisive role.

Future research lines could concern the outline and study of the design process; should some activities be added or changed in order to accommodate for the highlighted needs of the designers? Furthermore, pilots' view on their role as end user representatives and their participation in the design process activities could be investigated in more detail.

Acknowledgments This research was funded by NFFP (National Aviation Research Programme, NFFP6-2013-01201), which is founded by VINNOVA (Swedish Governmental Agency for Innovation Systems), the Swedish Armed Forces and the Swedish Defence Material Administration. The authors also like to thank Saab AB and the University of Skövde for supporting the project.

References

1. Alfredson, J., Andersson, R.: Designing for human factors in the technology-intensive domain of fighter aircraft. Int. J. Aviat. Technol. Eng. Manage. **1**(2), 1–16 (2013)
2. Bitik, A.B., Külünk, B.: Identification of Human Factors Concerns in Joint Strike Fighter and Training Recommendations, p. 161. Naval Postgraduate School, Monterey (2008)
3. Carroll, J.M., Rosson, M.B.: Participatory design in community informatics. Des. Stud. **28**, 243–261 (2007)
4. Cavaye, A.L.M.: User participation in system development revisited. Inf. Manage. **28**, 311–323 (1995)
5. Hirschheim, R., Klein, H.K.: Four paradigms of information systems development. Commun. ACM **32**(10), 1199–1216 (1989)
6. Hartwick, J., Barki, H.: Explaining the role of user participation in information system use. Manage. Sci. **40**(4), 440–465 (1994)
7. McKeen, J.D., Guimaraes, T.: The relationship between user participation and user satisfaction: an investigation of four contingency factors. MIS Q. **18**(4), 427–451 (1994)
8. ISO: Ergonomics of Human-System Interaction, in Part 210: Human-centered Design for Interactive Systems (2010)
9. Lallemand, C., Gronier, G., Koenig, V.: User experience: a concept without consensus? Exploring practitioner's perspectives through an international survey. Comput. Hum. Behav. **43**, 35–48 (2015)

10. Cherry, C., Macredie, R.D.: The importance of context in information systems design: an assessment of participatory design. Requirements Eng. **4**(2), 103–114 (1999). doi: 10.1007/s007660050017
11. Kujala, S.: User involvement: a review of the benefits and challenges. Behav. Inf. Technol. **22** (1), 1–16 (2003)
12. Singer, G.: Methods for Validating Cockpit Design, the Best Tool for the Task, p. 76. Department of Aeronautics, Royal Institute of Technology, Stockholm (2002)
13. Wilson, S., et al.: Helping and hindering user involvement—a tale of everyday design. In: CHI 97, Atlanta (1997)
14. Damodaran, L.: User involvement in the systems design process-a practical guide for users. Behav. Inf. Technol. **15**(6), 363–377 (1996)
15. Lynch, T., Gregor, S.: User participation in decision support systems development: influencing system outcomes. Eur. J. Inf. Syst. **13**, 286–301 (2004)

Development and Evaluation of Packaging Prototypes in a Teaching Context of Ergonomic Design: A Didactic Experience

Gabriel Bonfim, Fausto Medola and Luis Paschoarelli

Abstract The teaching of ergonomic design of packages requires an experience of prototype development that can be evaluated and compared with similar commercially available products. This study was aimed to report an experience of development and evaluation of consumable product packages in a teaching context of ergonomic design. Videos were recorded to assess the perceived usability of packages and prototypes. It was applied SUS and SD protocols to evaluate the products. The teaching experience in assessing consumer products packaging, the use of assessment parameters in the design of new packages and the development of prototypes that meet aesthetic, functional and especially ergonomic requirements, were expressively positive to the comprehension of the process by the actors (students) involved.

Keywords Teaching · Package design · Prototypes · Ergonomics

1 Introduction

The teaching of Ergonomics in a Design program aims to develop the students' skills of applying ergonomic knowledge in the product design, as well as evaluating the design of a given product from a usability perspective in a context of usage. Therefore, offering the students an experience of usability evaluation, benefits the learning process by complementing the application of ergonomic knowledge in the product design.

G. Bonfim (✉) · F. Medola · L. Paschoarelli
UNESP—Univ. Estadual Paulista, Av. Eng. Luis Edmundo Carrijo Coube 14-01, Bauru 17033-360, Brazil
e-mail: gh_cb@hotmail.com

F. Medola
e-mail: fausto.medola@faac.unesp.br

L. Paschoarelli
e-mail: paschoarelli@faac.unesp.br

M. Soares et al. (eds.), *Advances in Ergonomics Modeling, Usability & Special Populations*, Advances in Intelligent Systems and Computing 486,
DOI 10.1007/978-3-319-41685-4_6

Associated with the usability evaluation, it is necessary to provide experiences that apply the prototyping of products. Alcoforado Neto [1] describes a teaching experiment involving undergraduate students in design, in which the prototype was the object of analysis. Regarding the experience of teaching packaging design, which involves the prototyping process, Paschoarelli [2] reports two cases, in which the prototyping of new packages was essential to the overall assessment of the results (designs). In terms of ergonomic design context, the usability level in the interaction between users and packaging is an important parameter for the assessment of the project, which requires a greater integration and equalization among the stages of creation/development/evaluation.

This study was aimed to report an experience of development and evaluation of consumable product packages in a teaching context of ergonomic design. Additionally, it presents the use of two well established research tools—SUS and SD—as components of the usability evaluation applicable in the design process, in order to empower product ergonomics.

2 Teaching of Ergonomics in an Undergraduate Program of Design

The Undergraduate Program of Design at UNESP—Universidade Estadual Paulista (Sao Paulo State University) covers two main areas: Graphic and Product Design. The curriculum is distributed over four years with the choice of one habilitation by the student. The main axis of the Design Program is represented by projectual disciplines, which are focused on design practice and application of knowledge to solve problems. The other disciplines, such as the Ergonomics, extend the scientific knowledge of students, providing better conditions for the development of projects.

The discipline of Ergonomics Applied to Design (EAD) is offered in two parts (EAD I and EAD II) and they are part of the curriculum of the Undergraduate Program of Design at UNESP. While the EAD I course focuses on presenting the theoretical aspects of Ergonomics (physical, cognitive and organizational) applied to the design of products, systems and environments, the EAD II provides an experience of product development and evaluation based on ergonomic and usability concepts. Both disciplines—EAD I and EAD II—are offered in two consecutive semesters, with 60 h each.

This paper describes the teaching experience related to the activities that were carried out during the discipline EAD II, in 2015. A total of 28 students were enrolled and attended the course that was taught by two professors and one assistant.

3 Designing Ergonomically: The Case of Packaging Design

The discipline EAD II was carried out with an initial theoretical phase in which it was discussed usability concepts and its application in the ergonomic design process. At this point, students were introduced to the most used evaluation tools in usability studies, such as SUS [3] and SD [4].

As a second phase of the discipline, the students were separated in nine groups and they were asked to search for consumable products that are often used in daily routine. Each group of students was responsible to select two different packages of the same category of product. The selected categories of commercially available

Fig. 1 Packages chosen by the students

ESCALE								
SIMPLE	○	○	○	○	○	○	○	COMPLEX
UNAPPETIZING	○	○	○	○	○	○	○	APPETIZING
UGLY	○	○	○	○	○	○	○	BEAUTIFUL
RESISTANT	○	○	○	○	○	○	○	FRAGILE

Fig. 2 Part of an SD protocol

SENTENCES	ESCALE
The package design makes me realize how I use it and how it should be its handling!	Strongly disagree ○ ○ ○ ○ ○ Strongly agree
The materials used in the package are inadequate, because they do not convey safety and product quality!	Strongly disagree ○ ○ ○ ○ ○ Strongly agree
The information on the package is easy to read and allows us to understand the characteristics of the product!	Strongly disagree ○ ○ ○ ○ ○ Strongly agree
The colors of the package are inadequate and do not convey the quality of the packaged product!	Strongly disagree ○ ○ ○ ○ ○ Strongly agree

Fig. 3 Part of a SUS protocol

products were deodorant, milk, spaghetti, razors, ketchup, noodles, potato chips, wheat flour and cotton swabs. All the packages can be seen in Fig. 1.

With eighteen packages of nine categories of products (one category per group), it was discussed the main characteristics of the package design, considering the practical, aesthetic and symbolic aspect of them. This was an important part of the

Fig. 4 Example of a video recorded for a specific package

discipline, since the students were challenged to think about the entire process of the use of the product, from the purchasing at the supermarket to the disposal after the use.

This phase resulted in the definition of ten opposite pairs of adjectives and ten usability statements to be presented in the SD and SUS protocols, respectively. Figures 2 and 3 present an example of the evaluation tools for a specific category of product.

The professors responsible for the discipline recorded one video for each of the eighteen products, in which it was demonstrated the use process: opening, accessing the content and closure (Fig. 4).

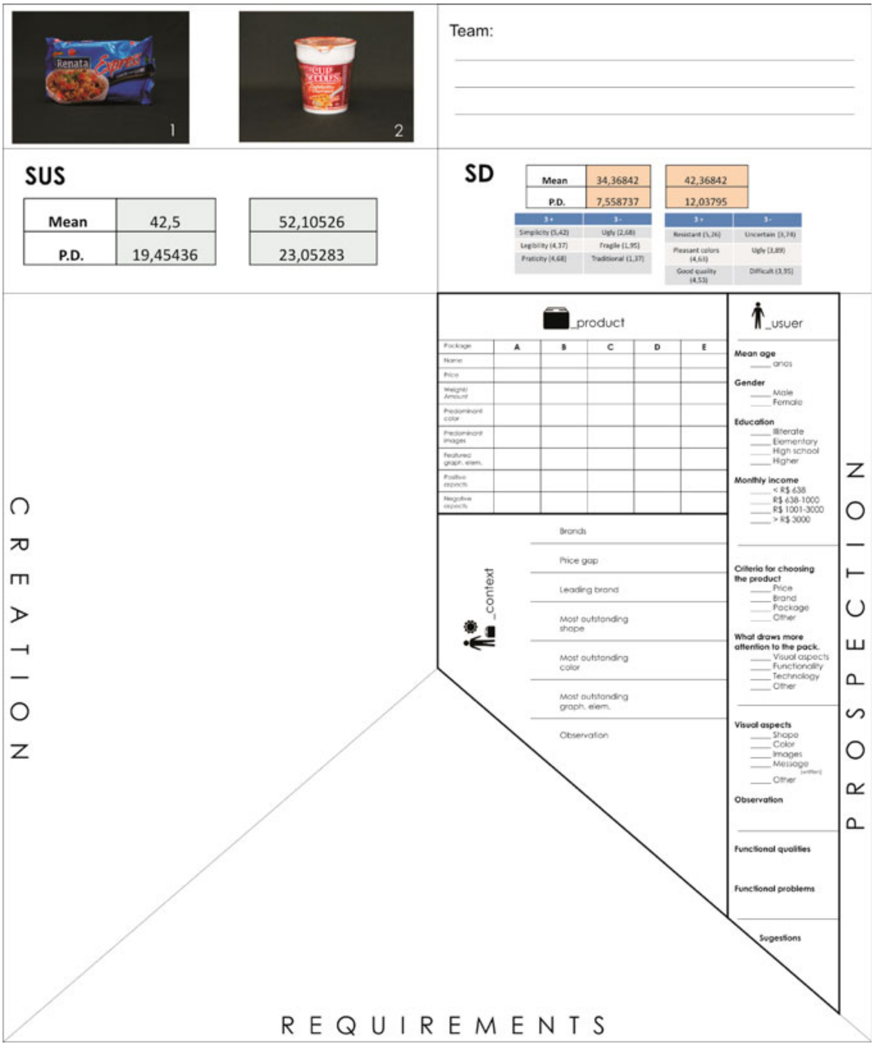


Fig. 5 Example of a panel

In the next class, the videos of the eighteen products were then presented to the students in a randomized order. Immediately after the video of each product, the students answered the SUS and SD protocols of the respective product. The professors then analyzed the results of all SUS and SD protocols and provided this information for each group of students.

After that, the students went to two supermarkets and collected data about the arrangement of the selected products on the shelf, the graphic and physical features of the package design, consumers' perceptions about positive and negative aspects of the packages. In addition, students collected data about general features of the products, such as size, shape, weight, price, among others.

All the information previously mentioned was gathered and presented in panels (Fig. 5) that were used to define the design briefing, which in turn, guided the students to start the design process of a new package for the same category of product, in order to solve or minimize the problems found in the evaluated packages, therefore favoring product usability.

It was given a period of two months for the students to work on the design of a new package and produce a prototype. The only requirement for the prototype was that it could simulate a real process of use. From the nine developed prototypes, three were excluded because they were not functional (Fig. 6), thus not allowing the simulation of use for subjective evaluation. Figure 7 presents the six prototypes that were eligible for the perceived usability evaluation.

Fig. 6 Prototypes excluded from the perceived usability evaluation (*1* ketchup, *2* deodorant, *3* milk)

Fig. 7 Prototypes eligible for the perceived usability evaluation (*1* spaghetti, *2* cotton swabs, *3* noodles, *4* razors, *5* wheat flour, *6* potato chips)

New videos were recorded with the six remaining prototypes, following the same procedures of opening, accessing the content and closure. All the videos were presented to the students in a random sequence and, after each video, subjects answered the SUS and SD protocol for the respective product.

The analysis of the SUS and SD protocols revealed that the prototypes were, in general, better evaluated than the commercially available products, indicating that the usability evaluation being a part of the design process contributed to improve the package design and, therefore, favoring the perceived usability.

4 Conclusion

The use of perceived usability evaluation in product ergonomic design process proved to be a successful experience to enable students to make design decisions based on usability evaluations with reliable instruments. Understanding the equation among creation, development and evaluation during the product design is essential in the formation of new designers.

Acknowledgments The authors would like to thank FAPESP (São Paulo Research Foundation, Process N.2014/23953-6) and CNPq (National Council for Scientific and Technological Development, Process N. 309290/2013-9).

References

1. Alcoforado Neto, M.G.: Metodologia de Design mediada por Protótipos. Dissertation (Doutorate in Design), UNESP—Univ. Estadual Paulista, Bauru (2014)
2. Paschoarelli, L.C.: Design de Embalagem: uma experiência didática no ensino do projeto de produto. In: Domiciano, C.L.C. et al. (eds.) Ensaios em Design: Ensino e Produção de Conhecimento, vol. 1, pp. 158–171. Canal 6, Bauru (2011)
3. Tullis, T., Albert, W.: Measuring the User Experience: Collecting, Analyzing, and Presenting Usability Metrics. Morgan Kaufman, Burlington (2008)
4. Brooke, J.: SUS: a "quick and dirty" usability scale. In: Jordan, P.W., Thomas, B., Weerdmeester, B.A., McClelland, A.L. (eds.) Usability Evaluation in Industry, pp. 189–194. Taylor and Francis, London (1996)

Usability in the Development of Packaging Design: Complementing the Subjective Evaluation

Gabriel Bonfim, Fausto Medola and Luis Paschoarelli

Abstract Nine different consumable products were evaluated: two packaging that already existed in the market; and nine prototypes developed as alternatives to those existing packaging. An SD protocol was applied with ten pairs of antagonistic adjectives; and a SUS protocol, with ten sentences for such products. Videos that showed the use process of each package and prototype were recorded. After watching the videos, participants answered the SD and SUS protocols. Results showed that the evaluation technique by SD and SUS, through videos, proved to be relevant. The prototypes that met aesthetic and functional requirements, and sought to minimize ergonomic issues, obtained expressive positive evaluations in both the SD and SUS protocols.

Keywords Package design · Usability · System usability scale · Semantic differential

1 Introduction

The usability of a product is one of the most significant characteristics for the device-user interaction be satisfactory. When those products are packages, the interactions with users may cause constraints or even serious accidents [1–4]. Studies developed by Bonfim and Paschoarelli [5] evaluated the usability of mouthwash packages with elderly subjects, and observed the difficulty of use for

G. Bonfim (✉) · F. Medola · L. Paschoarelli
UNESP—Univ. Estadual Paulista, Av. Eng. Luis Edmundo Carrijo Coube 14-01, Bauru 17033-360, Brazil
e-mail: gh_cb@hotmail.com

F. Medola
e-mail: fausto.medola@faac.unesp.br

L. Paschoarelli
e-mail: paschoarelli@faac.unesp.br

M. Soares et al. (eds.), *Advances in Ergonomics Modeling, Usability & Special Populations*, Advances in Intelligent Systems and Computing 486,
DOI 10.1007/978-3-319-41685-4_7

different types of openings. Such problems can be easily minimized if usability tests are applied during the development of packaging design.

At least two tools can serve as a parameter for the evaluation of usability tests: SUS (System Usability Scale) and SD (Semantic Differential). The SUS protocol was created in 1986 by John Brooke and it aims the subjective evaluation of usability. This protocol is designed to be simple and easy with ten statements related to the product. Half of the sentences is positive and the other half is negative, this is to avoid distortions in the response of subjects, causing the participants to read each statement and think whether they agree or not [6].

The SD protocol was created in 1957 by Charles Osgood, in order to measure the connotations of words or concepts. In addition, this technique has been used as a means of assessing the human-technology interface. The SD has pairs of opposite adjectives separated by a Likert scale, which may be composed of 5 or 7 anchors. Its evaluation is usually done by analyzing the mean values and the factor analysis [7].

Particularly, regarding the packaging design development, it is necessary for the prototypes, which will serve to perform the user-device interaction, to be functional, that is, they should allow the simulation of the main actions of use [8]. Moreover, it is not always possible to provide a large number of prototypes that can be effectively used by a number of participants required for usability tests. This is due, especially in those cases where access to the package—specially its opening—causes it to be discarded. In this case, an interesting alternative is to apply the principles of Perceived Usability [9, 10] which is nothing more than the evaluation of the interaction by visualizing the use process without tactile contact with the device.

This study aimed to evaluate the perceived usability during the demonstration of use simulation with prototypes and packages of consumable products, applying SUS and SD tools.

2 Materials and Methods

2.1 Subjects

The sample was comprised by twenty-eight (9 men and 19 women, mean age of 23.05 ± 1.87) undergraduate students of the Design course at the School of Architecture, Arts and Communication (UNESP—Univ. Estadual Paulista, Bauru, Brazil), that voluntarily participated in this study. Prior to the study, subjects were informed about the aims and procedures and signed an Informed Consent Form previously approved by the Ethical Committee of the School of Architecture, Arts and Communication—UNESP (Process 932.215/2015).

2.2 Materials

A total of twelve packages of consumable products were selected and divided in six pairs of the same product category, in order to be evaluated as part of a design process. Package selection was made taking into account its characteristics that might potentially result in usability problems (Fig. 1).

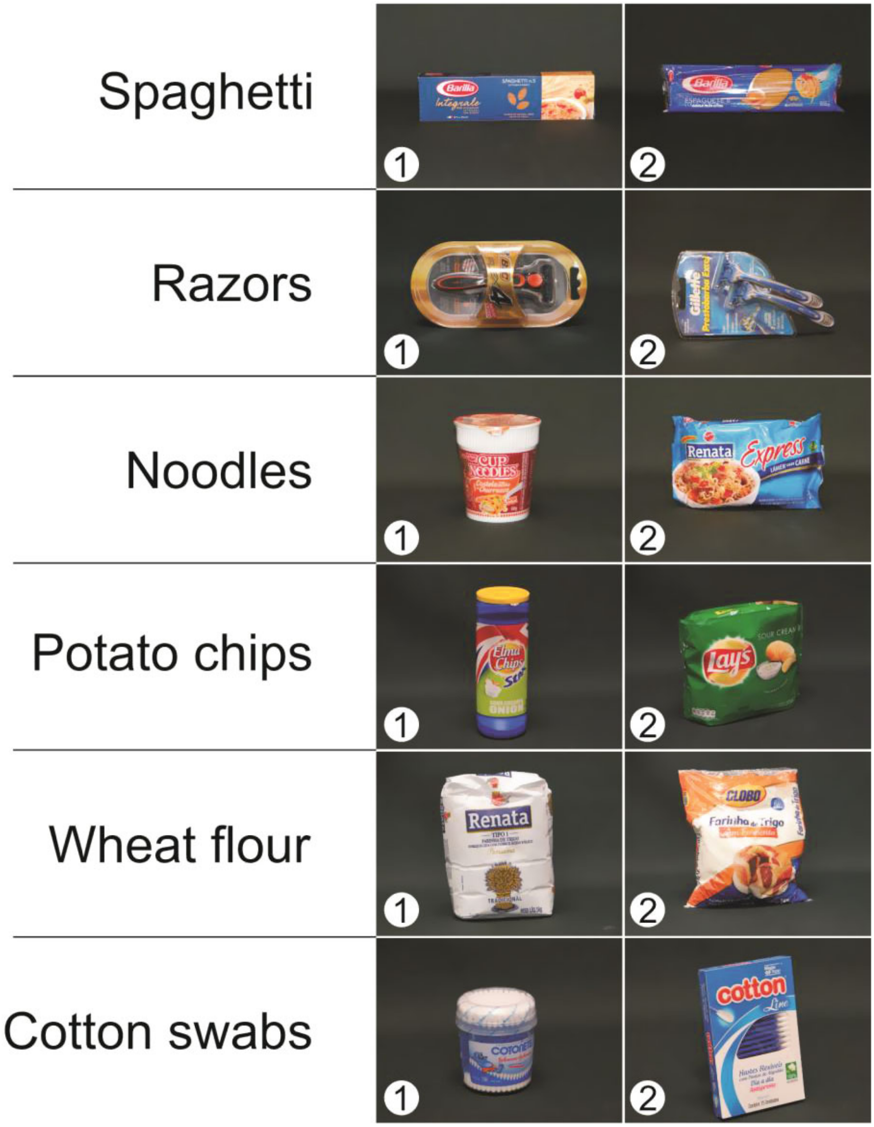


Fig. 1 Product categories and pairs of packages of consumable products

A video camera (Sony Cyber-shot DSC-HX1) was used to record the opening process of all the packages.

A System Usability Scale (SUS) protocol was used to assess the subjects' perception of the packages usability. This protocol was comprised by ten statements regarding how packaging design met the usability requirement. Subjects should mark in a 5-point scale their level of agreement with each statement. Additionally, a Semantic Differential (SD) protocol was developed with ten pairs of opposite adjectives related to practical, aesthetic and symbolic features of the packages. Those adjectives were separated by a 7-point scale in which the subjects should choose a point. The nearer the point was from one side of the scale, the stronger the subject's accordance with the adjective in that side.

2.3 Procedures

Subjects were divided in six groups, each of them working with a pair of packages of the same category of product. Videos were recorded with a specialist in ergonomic design showing the opening process of all the eighteen packages. Those videos were then presented to the subjects in a randomized order. After watching the opening of each package, subjects were asked to fulfill the SUS and SD protocols. Finally, the analysis of the results from SUS and SD provided information on usability issues of the evaluated packages. From this analysis, each group of students started the design process of a new package for the same product category aiming to solve or minimize the problems found in the evaluated packages. This process took two months and ended up with the development of a prototype of a new package.

New videos were recorded with the specialist in ergonomic design showing the opening process of the nine prototypes, that were then presented in a random order to the students and the same evaluation procedures were repeated (SUS and SD protocols).

2.4 Data Analysis

SUS score was obtained from the sum of the results of each statement multiplied by 2.5, resulting in a percentage value, as described by Tulis and Albert [7]. The SD scale varied from 1 to 7, where 1 was the correlated to the negative adjective and 7 to the positive one. Data is presented descriptively for both SUS and SD, in terms of average and standard deviation that were obtained from all the subjects.

3 Results and Discussions

This study reported on the use of two objective tools for the assessment of perceived usability in a product design process. We found that SUS and SD techniques are useful tools that complement users' subjective evaluation, as both were sensible to detect how different design of packages influence the usage process, especially the opening and closure stages.

The first evaluation of perceived usability (video based) showed that most of the packages had problems that might be potentially addressed in a new design proposal. The SUS and SD scores of all packages are presented in Table 1.

From the results of the first usability evaluation (commercial products) students started the design process of new packages related to the evaluated products. The prototypes were developed based on the previous results regarding the video based evaluation of perceived usability. Figure 2 presents the six prototypes for the perceived usability evaluation.

Results showed that both SUS and SD are useful evaluation tools and sensitive to differences in the design of consumable products packaging. Different results were found among the three evaluated packages (two commercially available and the prototype) with both SUS and SD.

From the six prototypes, 4 were better evaluated than the respective packages, revealing that the evaluations tools were able to highlight problems in the design of packages that might impact the usability.

The students addressed these issues in the design of the prototype, resulting in a more positive evaluation of perceived usability. Table 2 presents the detailed scores of SUS and SD for all the packages and prototypes.

Two of the prototypes had lower scores in both SUS and SD than one of the commercial products. It is hypothesized that graphical issues, such as visibility problems (lack of contrast), and ergonomic issues (grip size) could have affected negatively the perception of usability of these prototypes.

Table 1 SUS and SD scores of all packages

Package	SUS	SD
Spaghetti 1	63.16	48.68
Spaghetti 2	37.50	40.16
Razors 1	55.66	47.79
Razors 2	54.21	40.47
Noodles 1	52.10	42.36
Noodles 2	42.50	34.36
Potato Chips 1	76.31	56.31
Potato Chips 2	62.10	38.57
Wheat Flour 1	70.53	48.74
Wheat Flour 2	24.74	31.84
Cotton Swabs 1	87.37	60.10
Cotton Swabs 2	62.89	43.26

Fig. 2 Prototypes for the perceived usability evaluation

Table 2 SUS and SD scores of all packages and prototypes

	SUS	SD
Spaghetti Prototype	83.75	57.50
Spaghetti 1	63.16	48.68
Spaghetti 2	37.50	40.16
Razors Prototype	78.75	55.89
Razors 1	55.66	47.79
Razors 2	54.21	40.47
Noodles Prototype	81.62	51.88
Noodles 1	52.10	42.36
Noodles 2	42.50	34.36
Potato Chips 1	76.31	56.31
Potato Chips Prototype	73.33	51.00
Potato Chips 2	62.10	38.57
Wheat Flour Prototype	83.19	53.78
Wheat Flour 1	70.53	48.74
Wheat Flour 2	24.74	31.84
Cotton Swabs 1	87.37	60.10
Cotton Swabs Prototype	70.00	53.50
Cotton Swabs 2	62.89	43.26

SUS and SD have been used for the assessment of the interface between user and a variety of daily life products [5, 11] and assistive technology devices [12]. These studies demonstrate that the evaluation of perceived usability provides important contribution to the comprehension of the user-product interaction taking into account not only practical, but also aesthetic and symbolic aspects. This knowledge may favor the development of products whereas substantiate design innovation proposals.

This study provides additional knowledge to the areas of Product Design, Ergonomics and Usability. However, it has some limitations that must be noted. First, as the usability test was based on video presentation, the subjects did not interact with the packages and prototypes. The interaction with the products in a usability test in a real context would provide a more complete view of the entire process of package usage. Additionally, the students that developed the prototypes were the subjects of the perceived usability test, although they did not evaluated their own prototypes, in order not to influence the assessment.

4 Conclusion

This study showed that SUS and SD are valuable tools for the assessment of perceived usability of daily life products, as both were sensible to differences in practical, aesthetic and symbolic aspects of packaging design. In this context, these evaluation tools enabled the identification of problems and gaps in the design of packages of commercially available that could be further addressed in new design proposals. Indeed, the package prototypes that took into account ergonomic and graphic aspects, showed higher scores in both SUS and SD. The usability evaluation is an essential part of the ergonomic design process, contributing to the development of products that best meet users' needs, characteristics and expectations.

Acknowledgments The authors would like to thank FAPESP (São Paulo Research Foundation, Process N.2014/23953-6), CNPq (National Council for Scientific and Technological Development, Process N. 309290/2013-9).

References

1. Winder, B., Ridgway, K., Nelson, A., Baldwin, J.: Food and drink packaging: who is complaining and who should be complaining. Appl. Ergon. **33**, 433–438 (2002)
2. Spitler, V., Millis, A., Marcey, N., O'Brien, C.: Hazard Screening Report: Packaging and Containers for Household Products. Consumer Product Safety Commission, Washington (2005)
3. Zunjic, A.: Ergonomics of packaging. In: Karwowski, W., Soares, M.M., Stanton, N.A. (eds.) Human Factors and Ergonomics in Consumer Product Design: Uses and Applications, pp. 101–123. CRC Press, Boca Raton (2011)
4. Bonfim, G.H.C., Paschoarelli, L.C.: Visualization and comprehension of opening instructions in child resistant packaging. Procedia Manufact. **3**, 6153–6160 (2015)
5. Bonfim, G.H.C., Paschoarelli, L.C.: Comparison Between two child-resistant packages (CRPs) through a usability test with elderly people. In: Soares, M., Rebelo, F. (eds.) Advances in Ergonomics In Design, Usability & Special Populations Part III, vol. 18, pp. 438–448. AHFE Conference, Louisville (2014)
6. Brooke, J.: SUS: a "quick and dirty" usability scale. In: Jordan, P.W., Thomas, B., Weerdmeester, B.A., McClelland, A.L. (eds.) Usability Evaluation in Industry, pp. 189–194. Taylor and Francis, London (1996)
7. Tullis, T., Albert, W.: Measuring the User Experience: Collecting, Analyzing, and Presenting Usability Metrics. Morgan Kaufman, Burlington (2008)
8. Alcoforado Neto, M.G., Paschoarelli, L.C., Silva, J.C.P.: Prototype-centered design: for better interactive design process. In: Soares, M., Rebelo, F. (eds.) Advances in Ergonomics In Design, Usability & Special Populations, vol. 17, pp. 474–485. AHFE Conference, Louisville (2014)
9. Campos, L.F.A., Lanutti, J.N.L., Mattos, L.M., Inokuti, É.S., Paschoarelli, L.C.: Perception of products by different levels of interaction: a study with pruning shears. In: Soares, M., Rebelo, F. (eds.) Advances in Usability Evaluation Part I, vol. 1, pp. 399–408. CRC Press, Boca Raton (2012)
10. Campos, L.F.A., Paschoarelli, L.C.: Usabilidade percebida, inerente, aparente e experimentada: abordagens para o ergodesign. In: 13th Ergodesign and 13th USIHC. UFJF, Juiz de Fora (2013)
11. Lanutti, J.N.L., Campos, L.F.A., Pereira, D.D., Mattos, L.M., Inokuti, E.S., Paschoarelli, L.C.: Aesthetic and symbolic aspects versus usability: evaluation of daily use product—lemon squeezer. In: Soares, M., Rebelo, F. (eds.) Advances in Usability Evaluation, vol. 2, pp. 517–526. CRC Press, São Francisco (2012)
12. Lanutti, J.N.L., Medola, F.O., Gonçalves, D.D., Da Silva, L.M., Nicholl, A.R.J., Paschoarelli, L.C.: The significance of manual wheelchairs: a comparative study on male and female users. Procedia Manufact. **3**, 6079–6085 (2015)

Integrating UCD and an Agile Methodology in the Development of a Mobile Catalog of Plants

Maria Aguilar and Claudia Zapata

Abstract The integration of User Centered Design (UCD) and agile methodologies for software development is suitable to achieve software products with higher degree of usability. However there are few controlled experiments that can show the advantages and the approach of this integration. The present paper describes the whole process of integrate one of the popular agile methodologies, Extreme Programming (XP), with UCD applied to the construction of a software application. The project deals with a mobile application about the vegetation from Pontificia Universidad Católica del Perú that allows users to search, recognize and find plants around the university campus.

Keywords User centered-design · Usability · Agile methodologies · XP

1 Introduction

One of the main quality features of a software system is its usability [5]. Based on the international standard ISO 9241, the term usability is defined as "the degree to which a product can be used by specified users to achieve specific goals with effectiveness, efficiency and satisfaction in a specific context of use" [8]. For this reason, methodologies as User Centered Design (UCD) which aimed at achieving usability are really helpful.

On the other hand, agile methodologies for software development arise due to one of the problems of software engineering that has been discussed for many years, which is how software development activities must be performed in order to speed up results, reduce costs and get better solutions [15].

M. Aguilar · C. Zapata (✉)
Pontificia Universidad Católica del Perú, Lima, Peru
e-mail: zapata.cmp@pucp.pe

M. Aguilar
e-mail: m.aguilarv@pucp.pe

M. Soares et al. (eds.), *Advances in Ergonomics Modeling, Usability & Special Populations*, Advances in Intelligent Systems and Computing 486,
DOI 10.1007/978-3-319-41685-4_8

It may seem natural to include methods from UCD into Agile development projects. However, the integration of these two approaches is not well defined [4]. While UCD is focused on interaction design and keep constant contact with end users, agile methodologies cover the entire process throughout the lifecycle of the software project [4]. An important similarity between them is that they seek to satisfy the needs and goals of users [2], reason why their integration is suitable to be studied, in order to achieve products with higher degree of usability [19].

The present paper describes the integration of an agile methodology with UCD applied to the construction of a software application. The project deals with a mobile application about the vegetation from Pontificia Universidad Católica del Perú that allows users to search, recognize and find plants around the university campus. The purpose of the project was to analyze the process of integrate Extreme Programming (XP) with some methods from UCD, emphasizing iterative development cycles and user evaluations.

The project was conducted in three parts. The first one, where the requirements were raised through interviews with a representative group of end users, then personas and scenarios were constructed based on the user's needs and a prototype of the application was built for getting quick and frequent feedback before starting developing the application. In the second part, the application was divided into iterative cycles. At the end of each of these cycles, thinking aloud tests were performed to facilitate fixing many of the usability problems that arose throughout the construction of the application. Finally, in the third part, a user evaluation was conducted to analyze the usability of the obtained software.

The project allowed to analyze the advantages of integrating XP with UCD along the development lifecycle and showed how this integration facilitates developing a user-oriented software including a well distribution of the resources and getting better results.

This paper is distributed as follows. First, the concepts of User Centered Design and Agile Methodologies are given in order to have a general approach of the methodologies used in the project. Second, the development of the product software is described by explaining each element from the proposed integration between XP and UCD and the usability evaluation of the final product obtained. Finally, the results and the analysis of the integration during the project are presented.

2 User Centered Design (UCD)

The design based on user experience is a tendency that has been increasing in the last years. The success of the products depends on the level of satisfaction of the end users' needs and goals. This leads to put the user as the center of the design process of a product [13]. User Centered Design is an approach that represents the techniques, processes, methods and procedures to design usable products and systems, considering the user as the center of the process. The value of UCD is to achieve a greater degree of usability in software [14].

2.1 Usability

Usability is the software's quality that facilitates the use of it and helps user to fulfill their specific objectives efficiently and effectively [15]. It is said that a product is truly usable when the user is able to do what he wants, the way he expects and without any impediment or hesitation [14].

According to the international standard ISO/DIS 9241-11, usability is defined as "the degree to which a product can be used by specific users to achieve specific goals with effectiveness, efficiency and satisfaction in a specific context of use" [8].

Making usable products is part of the UCD discipline. The standard ISO 9241-210: 2010 provides requirements and recommendations for User-centered design and activities that take place throughout the lifecycle of interactive computer-based systems [9]. According to the Standard, UCD is an approach to the development and design of systems whose aim is to make interactive systems more usable, focusing on the use of the system, using human or ergonomic factors and usability techniques and knowledge [9].

2.2 Principles of UCD

Rubin and Chisnell [14] emphasize three basic principles of UCD which will be described below:

- **An early focus on users and tasks**

Besides identifying and categorizing users, it is recommended that users and the design team have direct contact throughout the development lifecycle of the product. Furthermore, it is important that the data collection from and about users has a structured and systematic approach and, in order to avoid misleading information, designers must be trained by expert interviewers before conducting any session.

- **Evaluation and measurement of product usage**

Special emphasis is placed on ease of learning and ease of use, through the entire process of design, development and testing with real users.

- **Iterative design and testing**

Design, modification and testing of the product should be an iterative process, allowing the full review and reconsideration of the first samples and ideas of the product design.

3 Agile Methodologies

Agile approaches are commonly used in the software development to help companies respond to unpredictable situations. They propose alternatives to traditional project management and offer opportunities to assess the direction throughout the development lifecycle. Agile methodologies are characterized by being iterative and incremental, as they focus on repeating short cycles as well as the functional product [10].

According to The Agile Manifesto, the principles of agile methodologies are [10]:

- Customer satisfaction by delivering useful software.
- Welcome changing requirements, even late in development.
- The functional software is delivered frequently (weeks rather than months).
- The functional software is the primary measure of progress.
- Sustainable development, able to maintain a steady pace.
- Daily and close cooperation between business managers and developers.
- Face to face conversation is the best form of communication.
- Projects are built around motivated individuals, who should be trusted.
- Constant attention to technical excellence and good design.
- Simplicity.
- Self-organizing teams.
- Regular adaptation to changing circumstances.

There are several agile methodologies, as SCRUM, Extreme Programming, Features Driven Development, Adaptative Software Development and Dynamic Software Development. However, in this project, the chosen methodology is Extreme Programming, which will be described below.

3.1 Extreme Programming (XP)

XP is a methodology of agile software development, which is based on four values that guide the entire project: simplicity, communication, feedback and courage. The way of planning and monitoring is used to decide what to do next and to predict when a set of desired functionalities will be delivered. Basically, software development is based on a series of small fully integrated versions that pass all the tests that have been defined [11].

According to Beck [1], XP focuses on the best programming practices, which are:

- Planning game: The customer decides the scope and deliveries of each version based on estimate times calculated by programmers.
- Small versions, which are conducted daily or monthly, which allows putting the system into production in a few months.

– The metaphor. The shape of the system is defined by a metaphor or a set of metaphors shared between the client and programmers.
– Simple design. At all times the design runs all tests, communicates everything that developers want to communicate, does not contain duplicate code and has the fewest possible classes and methods.
– Tests. Programmers write unit tests every minute and all must be executed properly.
– Refactoring. The system design is developed through transformation of the existing design that keeps all tests running.
– Programming in pairs. All production code is written by two people on a screen/keyboard/mouse.
– Continuous integration, allowing new code to be integrated into the present system in a few hours.
– Collective ownership. All programmers can improve any code anywhere in the system at any time if they have the opportunity.
– The client in place, which means taking the customer all the time with the team.
– 40 h per week. No one can work overtime because it would be a sign of problems to be solved.
– Open workspace. The team works in a large room with small cubicles.
– Only rules. The team can change the rules at any time as long as agree on how they evaluate the effects of variation.

This methodology has been chosen for this project because it suggests that software development can be affected by any changes that arise in the development lifecycle of a project and describes a series of practical actions to reduce the costs of changing software [1]. It should be noted that only a few methods and tools that are defined in this methodology are used, excluding one of the practices of XP which is working in pairs, as this project was carried out on an individual basis and the main objective is the observation of integrating this tool with UCD methods. Figure 1 shows the basic XP process [18].

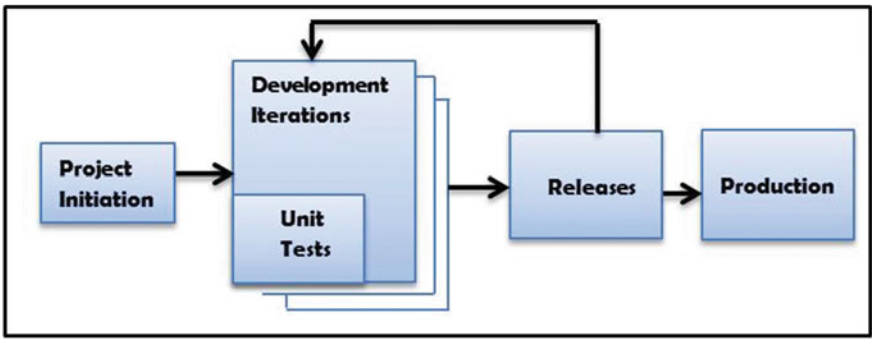


Fig. 1 Agile development process. Figure adapted from Wolkerstorfer et al. [18]

The development XP process is divided into iterations, which last roughly from 1 to 4 weeks and whose purpose is to deliver working software with added functionality to the customer [17]. At the beginning of each iteration, it takes place a Planning game, where the customer's requirements and user stories that are to be developed in the next iteration are chosen [17]. After that, acceptance tests for each user story are used to ensure that the stories have been precisely implemented [17]. It is worth mentioning that in this project the phases of release and production are not covered.

4 Proposed Integration

Figure 2 shows the basic XP process integrated with the UCD tools proposed in this project. This integration is based on a study case developed by Wolkerstorfer et al. [18] in which some tools are used to combine the advantages from XP with the advantages from the UCD process. The approach from the study case is an agile usability process, in which the XP misplacements are covered by the following proposed UCD tools: Unit testing for automated usability evaluations; Extreme Personas, a variation of the classic method of Personas used to state the user stories for XP; user studies, as investigation groups, interviews and diaries to know the final user; and expert usability evaluations.

In the proposed integration for this project, tools as interviews to study the final user, scenarios instead of user stories, personas, and usability evaluations for each iteration and for the final stage, when the product software is obtained, were chosen. According to Sohaib and Khan [17], user stories may not by useful enough form the usability perspective, this is why the decision of using scenarios, a usability technique, instead of user stories, which is the typical tool used in XP, was made. Obendorf and Finck [12] state that usability techniques have a major impact on agile software processes. They conclude that using Scenarios may involve and get better results from users because this method focuses on the user's needs and not on the functional software as is in the user stories [12].

4.1 Catalog of Plants

"Green areas from the campus of Pontificia Universidad Catolica del Peru [7] constitute an important natural heritage, as well as a particular system of diversity spreading abroad; therefore, it is necessary a capable technical management of them" [6]. The PUCP has an office of General Services, which is part of the Administration and Finance, which seeks to establish an Environmental Management System, considering a plan of biodiversity management. This plan states a register of the existing plants on campus, which were surveyed in mid-2013. Besides, there are other projects on course as the Garden Botanical Project [7], which aims to promote the biodiversity of the vegetation on campus.

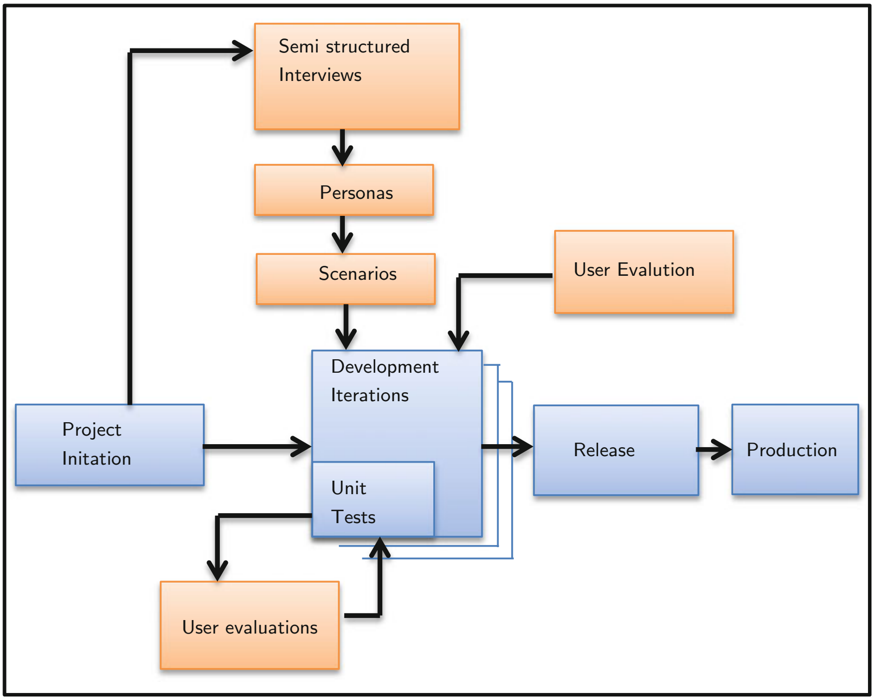


Fig. 2 XP process integrated with UCD tools proposed for this project. *Blue squares* are the stages of the basic XP process and *red squares* are the proposed UCD tools

For this reason, this project involves the design and development of a mobile application for a catalog of plants from PUCP, which could be used by students, faculty members and anyone interested in promoting or understand the diversity of plants from the University.

4.2 Applying the Proposal

First, the basic idea about what the application should do was raised through semi-structured interviews conducted with potential final users of the application. After that, the approach of Personas was performed to establish the groups of people who will interact with the product. Finally, Scenarios were created in order to support and bring the Personas to life. The transition from the initial stage to the process of iterations from XP was developed with the use of Scenarios, which were the output from the initial stage and a prerequisite for further development.

Semi structured interviews. For the research, semi structured interviews were used, in which a group of specific questions were established and the interviewer had the possibility to freely introduce additional questions in order to raise more information about users and the characteristics of the application. The interviewed selected were 3 Computer Science researchers from PUCP, members of the Group of Pattern Recognition and Artificial Intelligence Applied, currently working on a similar project with the biodiversity of endemic plants from the Amazon. They were classified as expert users of the application.

The interview was structured as follows: an introduction that stated the purpose of the interview, a section to raise basic information about the respondent and the use of applications on mobile devices, and a final section in which qualitative information on using catalogs applications of existing plants was collected. In this last section, a theoretical model known as Technology Acceptance Model (TAM), which attempts to explain and predict the acceptance of technological tools by a particular group of users in specific contexts [3] was used.

The results of these interviews allowed defining the list of requirements for the application. It was analyzed and corrected with the defined expert users of the application.

Personas. This tool was developed to increase empathy between end users and the development team. Each Persona represented a typical user group [18]. With the results of the interviews, 4 persons were identified, representing the 4 groups of users who will interact with the mobile application. As with the list of requirements, these user groups were designed and reviewed with the expert users.

Scenarios. Scenarios were developed as informal stories about the tasks and activities that were going to be performed by users. This technique is commonly used to express proposals or imaginary situations that help to design the concept of the application. Users are actively involved in creating these Scenarios [16]. Hence, with the Personas already defined, we proceed to create the Scenarios and involve users to refining them.

Iterations. As discussed previously, Scenarios are the output from the initial stage and a prerequisite to starting the implementation of the mobile application. Therefore, with the scenarios stated, four iterations were planned to build the application. Each iteration belonged to each of the main functionalities of the applications. According to XP, at the end of each iteration, functional tests were performed to ensure the adequate development of the requirements. Along with users, the stated requirements were prioritized to plan the features to be progressively implemented on next iterations. According to this plan, iterations 1, 2 and 4 were scheduled to last 1 week, and the iteration 3, 2 weeks. The time distribution was based, not only on the user's needs, but also on the development team availability.

Prototyping. According to the interviews and user groups already defined, we continue with prototyping. Before starting with the development of the application, it was necessary to construct a prototype, in order to clear the idea of the application functionalities. Paper prototyping was the chosen tool for this stage. As can be appreciated on Fig. 3, the main functionalities were shaped through this tool: A quick search by family, gender and specie name of the plants, a campus map to search plants by name and find their location on the University, a camera to take a picture of a plant's leave and find out its name and a section to give more information about the app.

Thinking aloud. The chosen technique performed at the end of each iteration, to ensure the properly development of the requirements from the user's point of view, was thinking aloud. This tool allows understanding the users' approach of the interface and the considerations that they have in mind when interacting with it [15]. The evaluation was conducted with the 3 users who were selected before as expert user and they tested the functionalities implemented on each iteration, giving their opinion and making sure to satisfy their goals.

Thinking aloud was a useful tool to integrate with XP in this project, since it is not quite complex and allowed users to easily adapt to the technique. As the iterations were developed, users began to express their opinions and thoughts in a much natural way, which helped to obtain better criticisms and observations about

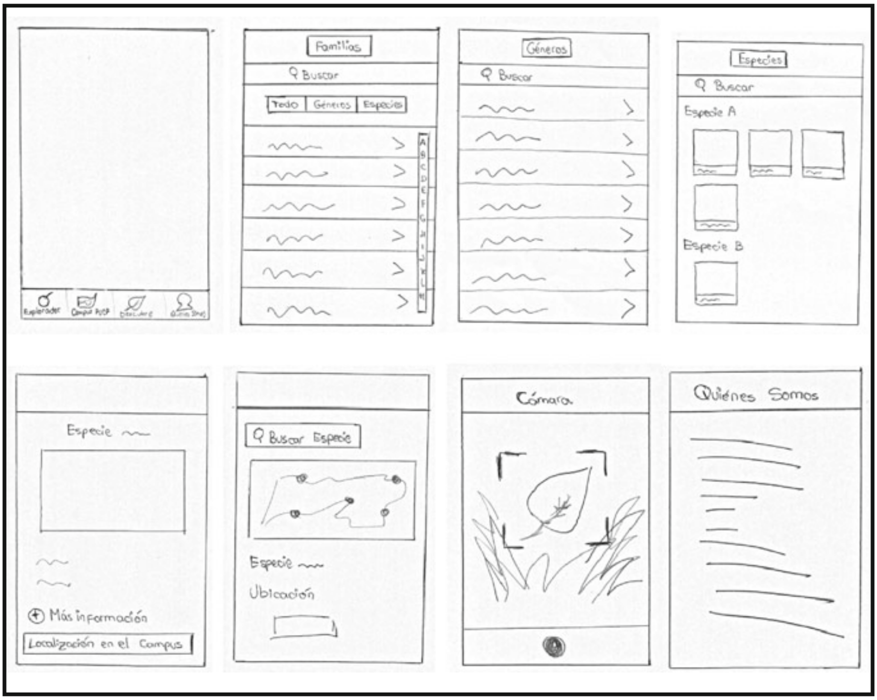


Fig. 3 Paper prototyping. The main functionalities of the mobile application were shaped through this tool

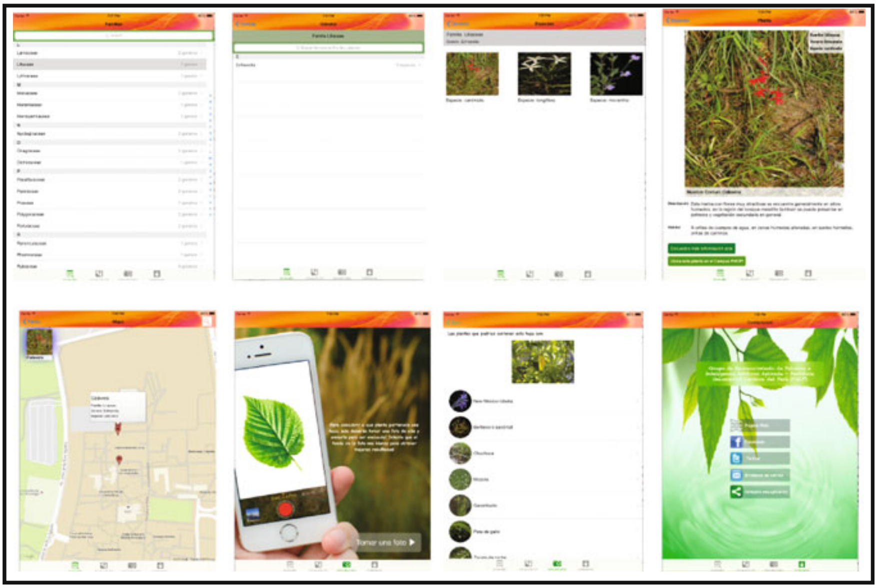


Fig. 4 Some screens taken from the mobile application developed on this project

the evaluated interface. Furthermore, thinking aloud tests were well integrated with functional tests, proposed by XP, as they allowed finding errors that were not found at first sight and it helped to ensure that it was building an acceptable functionally product.

Development of the application. The mobile application was developed on iOS platform with the use of an IDE called XCode. All the functionalities stated on the prototype were implemented through each of the 4 iterations. At the end of each one, there were performed functionality tests and thinking aloud evaluations, by giving an iPad to the users and testing the implemented functionality. All modifications and changes were documented and helped to evaluate every item included in the interface, which allow developing an application oriented to the users' satisfaction. Figure 4 shows some of the screens taken from the final version of the developed application.

5 Usability Evaluation

With the final version of the mobile application obtained, a user evaluation of the fully application was performed. The user evaluation chosen for this purpose was the one stated by Rubin and Chisnell [14], which proposes a less formal approach and allows obtaining qualitative information about the interface. The evaluation performed in this stage, included a comparison between the mobile application developed on the project with another existing application in the App Store, with similar functionalities, and thus, it allowed to analyze if we really obtained a usable product.

All tests were conducted in the laboratories from PUCP, participants received a device with iOS platform in which the two applications were installed. A task list was given to them and their interaction was observed when they performed each task. Likewise, a video recorder was used to keep track of the interaction and the comments from the participants along the evaluation. The chosen participants were 8 random people that represented each of the 4 user groups defined on the first stage of the project.

Some assessment measures were established in order to analyze the obtained information about the two applications. The results showed that all users were satisfied with both applications and they would be willing to use them again; however, the results and comments obtained, also showed that there was a slight preference for the application constructed in this project, which helped to confirm the idea that the implemented application actually contains more attractive and intuitive elements for the users.

The final results obtained after the evaluation showed that, applying the proposed integration for this project, we obtained a user oriented application, which successfully cover all the requirements defined at the beginning of the project.

6 Conclusions and Future Work

The techniques used during the analysis phase of the project were successfully integrated with XP. The interviews allowed knowing the end users and understanding their expectations. The approach of Personas and Scenarios helped to reinforce the idea of developing a customer oriented software and accurately plan iterations before starting with the implementation. Is worth mentioning that, in this process, feedback with users is very important, although the requirement list was defined at the beginning of the project, it was important to review it with users and ensure that everyone agree, and avoid making changes that could be more expensive in the future.

Usually, people does not spend much time on prototyping, however, it was noted that, besides being a very useful tool to shape the ideas of users and inexpensive to make changes, prototyping also allowed the developer to specify the functions to be implemented, considering the limitations of the project's resources (such as hardware or time) and analyzing what is or is not feasible to develop.

A very important issue discussed in this project is the relation between the iterations and the usability evaluations, which are an essential part of User Centered Design. Testing the software with users at the end of each iteration, allowed to test the usability of functional software in an early stage, where it is still possible to make changes. It is important to mention that this integration is intended to be successful if users are closely involved with the project, because we depend on the users' commitment and availability.

Finally, it is important to make a final usability evaluation to complement the user evaluations performed on each iteration, and thus ensure that the product is built oriented to customers.

As future related work, the proposed integration in this project could be applied to a bigger development project and evaluate if same results are obtained. As well as applying the same experience with other platforms as a web system or a different mobile platform than iOS, which will allow comparing the obtained results about the integration of UCD and Agile Methodologies but in different technologies.

References

1. Beck, K.: Embracing change with extreme programming. Computer **32**(10), 70–77 (1999)
2. Da Silva, T.S., et al.: User-centered design and agile methods: a systematic review. In: Proceedings—2011 Agile Conference, Agile, pp. 77–86 (2011)
3. Davis, F.D.: Perceived usefulness, perceived ease of use, and user acceptance of information technology. MIS Q. 319–340 (1989)
4. Ferreira, J., et al.: Agile development iterations and UI design. Presented at the Agile Conference (AGILE), 2007 (2007)
5. IEC, I.: ISO/IEC 25000. Software product quality requirements and evaluation (SQuaRE). Int. Organ. Stand. 41 (2005)
6. Ing. Javier Salazar Carbajal, Coordinador del Área de Gestión Ambiental y Jardines (OSG-DAF): Nuestra mira es establecer un Sistema de Gestión Ambiental en la PUCP, http://vicerrectorado.pucp.edu.pe/administrativo/opinion/contamos-con-un-registro-de-plantas-en-el-campus/ (2013)
7. INTE-PUCP: INTE-PUCP, http://inte.pucp.edu.pe
8. ISO, W.: 9241-11. Ergonomic requirements for office work with visual display terminals (VDTs). Int. Organ. Stand. (1998)
9. ISO, W.: 9241-210: 2010. Ergonomics of human system interaction-part 210: human-centred design for interactive systems. Int. Organ. Stand. (2010)
10. Beck, K., et al.: Manifesto for Agile Software Development (2001)
11. Lindstrom, L., Jeffries, R.: Extreme programming and agile software development methodologies. Inf. Syst. Manag. **21**(3), 41–52 (2004)
12. Obendorf, H., Finck, M.: Scenario-based usability engineering techniques in agile development processes. In: CHI'08 Extended Abstracts on Human Factors in Computing Systems, pp. 2159–2166. ACM (2008)
13. Pratt, A., Nunes, J.: Interactive Design: An Introduction to the Theory and Application of User-Centered Design. Rockport Pub (2012)
14. Rubin, J., Chisnell, D.: Handbook of Usability Testing: How to Plan, Design, and Conduct Effective Tests. Wiley (2008)
15. Salvador, C., et al.: A systematic review of usability techniques in agile methodologies. In: Proceedings of the 7th Euro American Conference on Telematics and Information Systems, pp. 17:1–17:6. ACM, New York, NY, USA (2014)
16. Sharp, H.: Interaction Design. Wiley (2003)

17. Sohaib, O., Khan, K.: Incorporating discount usability in extreme programming. Int. J. Softw. Eng. Appl. **5**(1), 51–62 (2011)
18. Wolkerstorfer, P., et al.: Probing an agile usability process. In: CHI'08 Extended Abstracts on Human Factors in Computing Systems, pp. 2151–2158. ACM (2008)
19. Zapata, C.: Integration of usability and agile methodologies: a systematic review. In: Marcus, A. (ed.) Design, User Experience, and Usability: Design Discourse, pp. 368–378. Springer (2015)

Collecting Data of SNS User Behavior to Detect Symptoms of Excessive Usage: Development of Data Collection Application

Ploypailin Intapong, Tiranee Achalakul and Michiko Ohkura

Abstract Worldwide use of social networking sites (SNSs) continues to dramatically increase. People are spending unexpected and unprecedented amounts of time online. However, many studies have warned about the negative consequences of excessive SNS usage, including the potential of addictive behavior. Therefore, detecting the symptoms of excessive SNS usage is necessary. Data collection is an important first step for analyzing the usage behavior of SNSs. This article describes the development of a data collection application. We employed questionnaires to gather user experiences of SNS and APIs to retrieve SNS data by focusing on Twitter and Facebook. Unfortunately, these methods are limited. Self-report data might be inaccurate. Also, some data on SNSs might not be collectable by APIs. Thus, we will collect more data from internet service providers (ISPs). The obtained data from our application will be applied to detect the symptoms of excessive use of SNSs and develop prevention strategies.

Keywords Social networking sites · User behavior · Social network addiction

P. Intapong (✉)
Graduate School of Engineering and Science, Shibaura Institute of Technology,
3-7-5 Toyosu, Koto-ku, Tokyo 135-8548, Japan
e-mail: nb15508@shibaura-it.ac.jp

T. Achalakul
Department of Computer Engineering, King Mongkut's University of Technology Thonburi,
126 Pracha-Uthit Rd., Bangmot, Thung-Khru, Bangkok 10140, Thailand
e-mail: tiranee@cpe.kmutt.ac.th

M. Ohkura
College of Engineering, Shibaura Institute of Technology,
3-7-5 Toyosu, Koto-ku, Tokyo 135-8548, Japan
e-mail: ohkura@sic.shibaura-it.ac.jp

M. Soares et al. (eds.), *Advances in Ergonomics Modeling, Usability & Special Populations*, Advances in Intelligent Systems and Computing 486,
DOI 10.1007/978-3-319-41685-4_9

1 Introduction

Digital technology plays an important role in daily life. Mobile and Social Networking Sites (SNSs), which are the next wave of the digital revolution, have become a popular type of communication where groups of people virtually meet and interact with others with similar interests.

In 2015, the use of SNSs dramatically rose 12 % from 1.9 billion to 2.1 billion active users, an astonishing total that equals almost 30 % of the world's population [1]. People use SNSs for many activities and purposes, including checking messages and comments and playing games. However, some people spend too much time on SNSs and use them in ways that are becoming excessive and/or addictive.

The excessive use of SNSs can cause emotional, relational, health-related, and performance problems, especially the risk of addiction. For these reasons, we should understand how people interact with them. Collecting data is an important first step for analyzing the individual usage behaviors of SNSs.

In this article, we describe the development of a data collection application, which aggregates data from self-report questionnaires and SNSs. Self-report questionnaires uses for gathering user experiences with SNSs. SNS data are retrieved through APIs provided by SNSs. Currently, we focus on Twitter and Facebook. Unfortunately, these methods have some limitations. Thus, alternative methods: for example, tracing network traffic or deploying a monitoring application might be employed in future research to get all of the aspects of SNS usage behavior.

We will analyze the obtained data from the application to clarify the relationships and characteristics of SNS usage. We will also use our analysis results for detecting the symptoms of excessive SNS use and developing strategies for preventing it.

2 Literature Review

2.1 Social Networking Sites

Social networking sites are virtual communities where groups of people with similar interests can create individual public profiles and interact with others [2]. However, researchers define and describe them in different ways. Ellison and Boyd [3] argued that "Terminology varied widely with the interchangeable use of 'social networking sites', 'online social networks' or even simply, 'social network' to refer to a diffuse—and sometimes improbable—range of sites and services." Ellison [4] defined social network sites as "web-based services that allow individuals to (1) construct a public or semi-public profile within a bounded system, (2) articulate a list of other users with whom they share a connection, and (3) view and traverse their list of connections and those made by others within the system." Ellison and

Boyd [3] argued that the term Social Network Sites is the most accurate because it emphasizes the role of networks, unlike previous online interaction spaces.

2.2 Negative Consequences of Excessive SNSs Usage

Many studies have suggested that excessive SNS usage leads to various negative consequences. According to Kuss and Griffiths [2], excessive SNS usage causes relationship problems and impacts academic and work performances. For instance, people who spend excessive time on SNSs appeared less involved in their real life communities and Facebook users had lower grades than students who did not use it because they were easily distracted and exercised poor time management. Al-Menayes et al. [5] concluded that Kuwaiti university students who spend too much time on SNSs had lower grades. In Thailand, many teenagers suffer from the negative effects of excessive SNS usage, such as a lack of sleep, reduced academic performance, inappropriate manners, negative emotional expressions, impairment of family and social functions, and mental health problems [6]. Excessive SNS usage delays bedtimes and reduces sleep quality [7].

2.3 Existing Data Collection Methods

Since SNSs have become so popular, many researchers have sought to understand their user behavior by collecting the data of SNS usage behavior. Many types of data and collection methods exist. Abdesslem et al. [8] summarized the methods for collecting data from SNSs and users as follows:

Self-report data. A common methodology to gather self-report data is to directly ask users about their experiences through questionnaires. Most researchers have employed this method in their studies for various purposes [5, 9–12]. It can gather difficult to obtain or expensive data as well as saving time. It can also be implemented on large samples as web questionnaire systems [11]. However, research in human behavior areas argued that self-report measures are inaccurate when compared to actual behavior [8, 13].

SNS measurement. The most common way to directly retrieve data from SNSs is to use the application programming interfaces (APIs) provided by SNSs. For instance, Facebook provides Graph API as the primary way to get data in and out of its platform [14], and Twitter provides REST API to read and write its data [15]. However, some of the data available on SNSs cannot be collected through APIs.

Some studies employ automated script that automatically scans and crawls content from websites using HTTP requests/responses [16]. Similarly, other researchers collect data through a social network aggregator [16, 17], which organizes and maintains the data of multiple social network accounts under a single username. User activities from one site are automatically synchronized to all other sites. Other researchers collect data by tracing network traffic from internet service providers (ISPs). All internet activities are recorded as log data by ISPs [8].

Application deployment. Deploying a monitoring application is another way of obtaining SNS user behavior [13]. Monitoring applications record and log the operations and activities of users while they are using computers or smartphones. The monitored data can be stored on local computer and cloud services. Abdesslem et al. [8] praised this method because it provides flexibility and privacy for data access. Unfortunately, it has some limitations. Researchers need to install applications on user devices to manually get data from them. Even though some cloud-based applications exist, most are commercial and limit the number of monitoring devices.

3 Design Framework

3.1 Conceptual Design

Overview. Collecting data from different sources further improves data analysis. In our design, we collect data for analysis from self-report questionnaires, SNS data, and ISP logs. In addition, alternative methods might be employed in future research. Figure 1 shows our conceptual design for collecting data.

Our data collection application, which is a web-based application designed for aggregating data for analysis from questionnaires and SNSs, has two parts: questionnaire and quizzes. Figure 2 shows an overview of this application that can also be called client-server architecture.

Questionnaire. Self-report questionnaires are employed for gathering the user experiences of SNSs. We designed them for gathering personal information, SNS usage information, and SNS addictive behavior. We also experimentally validated their content and usability. The results showed that they provide appropriate usability as an instrument for gathering data [18].

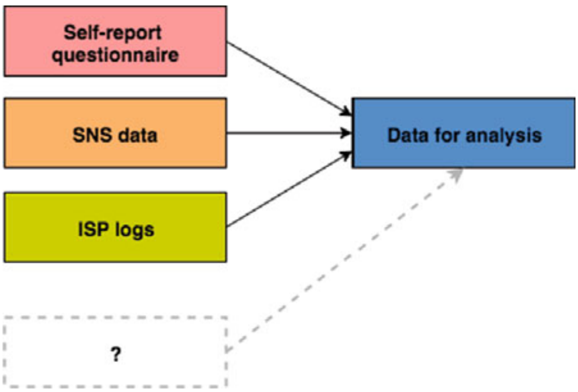


Fig. 1 Conceptual design for collecting data for analysis

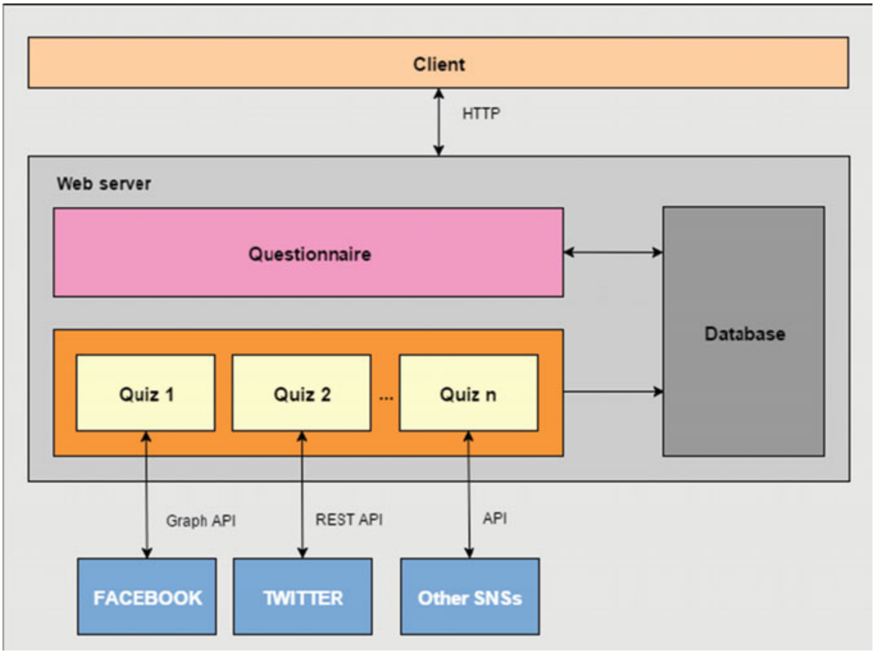


Fig. 2 Overview of data collection application

Quizzes. Quizzes are small games that ask questions, for example "What words do you use most often on Facebook?" Users do the quizzes and get results, which are retrieved from SNSs. Quizzes engage and motivate users for retrieving data from SNSs and query data through APIs provided by SNSs. Each SNS provides different APIs. At the beginning, we retrieved SNS data from Twitter and Facebook.

ISP. Since self-report data might be inaccurate, and some data available on SNSs might not be collected by APIs [8, 13], we retrieve data from ISPs. At the beginning, we will trace the network traffic data from the computer center of the Shibaura Institute of Technology (SIT) in Japan.

Privacy Issue. Privacy concerns should be considered in our development. Users should be notified about the obtained data. Thus, we provided privacy policy information and terms of use and requested users to accept the terms of agreement before the data collection process, as we describe in the next section.

3.2 Architecture Design

The architecture shown in Fig. 3 can be referred to as client-server architecture, which is software architecture that describes communication between clients and

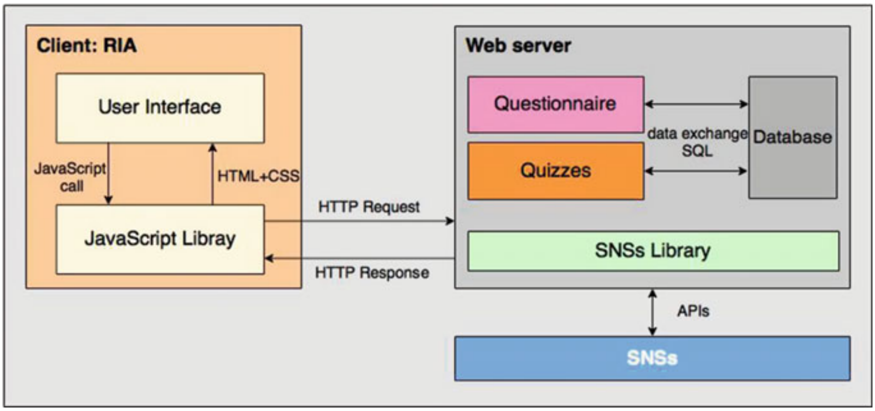


Fig. 3 Architecture overview of data collection application

servers. When users interact with the application by web browsers, the clients initiate a request to servers that send responses by HTTP protocols. The communication on the client's side occurs within a rich internet application (RIA), which has the characteristics of a browser-based application. RIA provides opportunities to reduce the load on web servers.

For the questionnaires in Fig. 3, the interactions between users and web interfaces, such as clicking buttons and validating forms, are handled by JavaScript library, which communicates with the web server by the HTTP protocol. For the quizzes in Fig. 3, the user interactions are also handled by the JavaScript library. Then the web server requests an authorization with SNSs and redirects the users to authenticate the pages of SNSs by API. The concept of the authorization process is illustrated in Fig. 4.

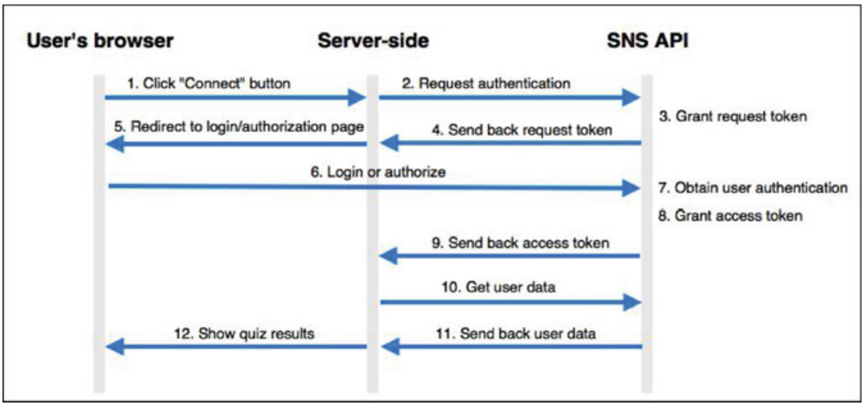


Fig. 4 Communication overview with SNS by API

4 Implementation of Data Collection Application

Based on the design framework, we implemented a data collection application, whose development is based on a bootstrap framework and a PHP platform. Bootstrap is used as a front-end framework, which combines HTML, CSS, and JavaScript and supports responsive screens from small mobiles to large desktops. PHP is used as a server scripting language.

4.1 Questionnaire

Based on the design, we divided our questionnaire into three sections: personal information, social network usage, and social network behavior. Before completing the questionnaires, users must accept the terms of agreement and then read the instructions. The interactions, navigation, and form validation of the questionnaire are handled by JQuery (JavaScript library). The questionnaire data are asynchronously sent to the server-side using Ajax in a JSON format (in the background). The following data are collected from the questionnaires:

- Demographic information (age, gender, and nationality)
- Purpose of use
- Length of use
- Frequency of use
- Time spent
- Place of use
- Device of use
- Potential of addictive behavior.

4.2 Twitter Quiz

Twitter provides two APIs [15] for accessing its data: REST API and Streaming API. The Streaming API is appropriate for long-running requests, which are in real-time. However, since real-time APIs are not necessary for our study, we chose the REST API for retrieving Twitter activities in our implementation.

The REST API identifies Twitter applications and users using OAuth authentication and uses an HTTP-based communication interface. This API provides two operations: read and write for accessing Twitter data and response data in a JSON formation. When developing a Twitter quiz, first, we have to register for a Twitter application and set up application details including OAuth settings.

Before starting the Twitter quiz, users have to accept the terms of agreement and be verified by Twitter. Users' browsers are redirected to the Twitter page in this process and back to our application after authentication is completed. We collected the following Twitter activity data by API:

- Tweets
- Retweets
- Replies
- Favorites or likes.

We can also get the action time of each activity except favorites/likes. Moreover, we collected Twitter user profiles for the following background of Twitter usage:

- Number of followers
- Number of friends or followers
- Number of tweets (posts)
- Number of favorites or like actions
- Date of joining Twitter.

4.3 Facebook Quiz

Facebook provides APIs [14] for accessing its data. Graph API is the primary way to access data on the Facebook platform based on HTTP. This API has multiple versions. In our implementation, we used Graph API version 2.5, which is the latest version published in 2015.

Most Graph API requests require an access token, which is "an opaque string that identifies a user, app or page" [14], generally obtained in the OAuth authentication process. When developing a Facebook quiz, first, we have to create a Facebook application and set up its details. App IDs and secrets are generated in this step.

Before starting the Facebook quiz, users have to accept the terms of agreement and be verified by Facebook. When authentication is completed, we collect Facebook activity data, which we can only get in the following user feed (user profile page):

- Posts
- Comments
- Likes.

We can get the action time of each activity except likes. Additionally, we collected Facebook user profiles for the background of Facebook usage. The following data are available:

- Number of friends
- Gender
- Birthday
- Location/hometown.

The process of retrieving the data of the questionnaires, Twitter, and Facebook runs as a background script. Finally, we store the data in our database and show the results of quizzes on a web interface.

The data collection application allows users to complete questionnaires and/or quizzes without site authentication. Since mapping these data from the same user is useful, we use cookies, which are files with a small amount of data, to store unique identifiers for each user. When the first user's data are stored in our database, the application generates a unique number and sets a cookie value and an expired time. Then the cookies are sent to the user browsers and stored on computer hard drives. If the same user completes another questionnaire or quiz, the data are stored with the existing unique identifiers. In addition, employing a cookie technique partly prevents data duplication from identical users who do questionnaires and quizzes in the same period.

5 Limitations of Data Collection

Various methods have been employed for aggregating data. Nevertheless, these methods have limitations.

Inaccuracy of self-reported information. Self-report data might inaccurately represent user behavior compared to actual behavior. Questionnaire participants might overlook or downplay their SNS experiences and inaccurately report information. However, self-report data might be useful where data cannot be collected from other sources.

Restriction of SNS APIs. Some data available on SNSs cannot be collected through APIs. SNS APIs are insufficient to capture all SNS activities, especially reading activities.

The following are the limitations of the Twitter REST API:

- We cannot get the action times of favorites/likes.
- Twitter does not allow request operations with data period conditions.
- Twitter limits the number of request operations to 15 requests per window.
- Return data are limited to 200 records per request and up to 3200 records.

The following are the limitations of the Facebook Graph API:

- Activity data are available only on the user feeds on the profile page since API versions after 2.0 do not support Facebook Query Language (FQL).
- We cannot get the action time of likes.
- The latest APIs do not support the new reactions: love, haha, wow, sad, and angry.

Furthermore, SNSs continue to update the versions of their APIs. Developers should migrate their applications with new updates, or otherwise some commands will work incorrectly or maybe not at all.

Due to the limitations of self-report measures and SNS APIs, alternative methods will be employed in the future to improve data analysis.

6 Conclusion

Collecting data is an important first step for analyzing SNS user behavior. In this article, we presented the development of a data collection application. A single data collection method is inadequate to capture all of the aspects of SNS usage behavior. Collecting data from different sources improves data analysis. Our application collects data from self-report questionnaires and SNS APIs. In the implementation, the data collection application retrieves SNS data from Twitter and Facebook.

Even though these methods have benefits for collecting data, they also have limitations. Self-report measures might be inaccurate when compared to actual behavior. Similarly, some data cannot be retrieved due to API restrictions. We will employ alternative methods in the future to improve data analysis and our application to obtain data to analyze SNS usage behaviors. The results will be applied to detect the symptoms and prevent the excessive use of SNSs.

References

1. We Are Social: http://wearesocial.net
2. Kuss, D.J., Griffiths, M.D.: Online social networking and addiction—a review of the psychological literature. Int. J. Environ. Res. Public Health **8**(9), 3528–3552 (2011)
3. Ellison, N.B., Boyd, D.M.: Sociality through social network sites. In: The Oxford Handbook of Internet Studies, pp. 151–172 (2013)
4. Ellison, N.B.: Social network sites: definition, history, and scholarship. J. Comput. Mediated Commun. **13**(1), 210–230 (2007)
5. Al-Menayes, J.J.: Dimensions of social media addiction among university students in Kuwait. Psychol. Behav. Sci. **4**(1), 23 (2015)
6. Phanasathit, M., Manwong, M., Hanprathet, N., Khumsri, J., Yingyeun, R.: Validation of the Thai version of Bergen Facebook addiction scale (Thai-BFAS). J. Med. Assoc. Thai. =Chotmaihet thangphaet **98**, S108–S117 (2015)
7. Andreassen, C.S., Torsheim, T., Brunborg, G.S., Pallesen, S.: Development of a Facebook addition scale. Psychol. Rep. **110**(2), 501–517 (2012)
8. Abdesslem, F., Parris, I., Henderson, T.: Reliable online social network data collection. In: Computational Social Networks, pp. 183–210. Springer, London (2012)
9. Burke, M., Marlow, C., Lento, T.: Social network activity and social well-being. In: Proceeding of the SIGCHI Conference on Human Factors in Computing Systems, pp. 1909–1912. ACM (2010)
10. Geisel, O., Panneck, P., Stickel, A., Schneider, M., Müller, C.A.: Characteristics of social network gamers: results of an online survey. Front. Psychiatry **6**, 1–5 (2015)

11. Masters, K.: Social networking addiction among health sciences students in Oman. Sultan Qaboos Univ. Med. J. **15**(3), 357–363 (2015)
12. Sagioglou, C., Greitemeyer, T.: Facebook's emotional consequences: why Facebook causes a decrease in mood and why people still use it. Comput. Hum. Behav. **35**, 359–363 (2014)
13. Junco, R.: Comparing actual and self-reported measures of Facebook use. Comput. Hum. Behav. **29**(3), 626–631 (2013)
14. Facebook Developers: https://developers.facebook.com/
15. Twitter Deveopers: https://dev.twitter.com/
16. Benevenuto, F., Rodrigues, T.: Characterizing user behavior in online social networks. In: Proceedings of the 9th ACM SIGCOMM Conference on Internet Measurement Conference, pp. 49–62 (2009)
17. Virmani, C., Pillai, A., Juneja, D.: Study and analysis of social network aggregator. In: Optimization, Reliability, and Information Technology (ICROIT), 2014 International Conference, pp. 145–148. IEEE (2014)
18. Intapong, P., Achalakul, T., Ohkura, M.: Collecting data of SNS user behavior to detect symptoms of excessive usage: design of data collection application. In: International Symposium on Affective Science and Engineering (ISASE) (2016) in press

Part II
Applied Design, Modeling and Usability Evaluation II

Seamless User Analysis with Integrated User Models in a Usability Engineering Repository

Anna Hüttig and Michael Herczeg

Abstract The analysis of users and their needs is one of the most important and most difficult aspects in software development. There have been many suggestions and usability engineering procedures published that are meant to clarify and consider the target users for a software product. However, all of these methods are weak in supporting the whole process of user analysis, and along the development process chain, the project team faces many problems. With our Usability Engineering Repository UsER we want to foster the practical use of a broad spectrum of usability engineering methods using a flexible approach of modular tools that are easy to handle. By explicit integration of user analysis results in all project phases we aim for continuous focus on user needs.

Keywords Human factors · Personas · Software engineering · Systems engineering · Tool support · Usability engineering · User analysis · User classes · User model

1 Introduction

Besides its functionality, the usability of a system has evolved to a key factor for corporate performance by better customer satisfaction and development of sales [1, 2]. To achieve higher grades of usability, it is essential to determine the relevant context of use before specifying detailed software requirements.

Especially, the analysis of the different users of the software system, their needs and capabilities seems to be a central aspect. The development and distribution of methods to support this area of analysis have evolved in the last years but still lack a

A. Hüttig (✉) · M. Herczeg
Institute for Multimedia and Interactive Systems, University of Luebeck, Ratzeburger Allee 160, 23562 Luebeck, Germany
e-mail: huettig@imis.uni-luebeck.de

M. Herczeg
e-mail: herczeg@imis.uni-luebeck.de

M. Soares et al. (eds.), *Advances in Ergonomics Modeling, Usability & Special Populations*, Advances in Intelligent Systems and Computing 486,
DOI 10.1007/978-3-319-41685-4_10

systematic and consequent transfer into development processes and the products developed. Particularly, the ongoing consideration of user needs and the continuous adjustments of inappropriate design decisions after first analyses are often neglected.

Comprehensive usability engineering processes found in literature also emphasize the need for continuous user focus but lack concrete descriptions for practical application and flexibility to integrate proposed methods into exiting software development workflows [3, 4].

User models in particular are suited to support software development in many ways. They are a promising method to encounter the primary challenges of practical usability engineering since the need and added value for this method can be easily communicated compared to many other usability engineering activities. However, user modeling varies in effort and usage. Hence, initial hurdles can be kept low while offering the potential to be consulted and refined throughout all project phases. Serving as independent artifacts, user models can be used as a foundation for discussion and can be combined with other usability methods. This fosters the required steady user focus [5].

For the modeling of users several techniques have been developed: Whereas in *usage-centered design* more abstract models like *actors* or *role descriptions* are used to analyze usage patterns [6], *user-centered design* aims for more realistic models. An obvious first step to handle the diversity of users is their division into *user classes* [7]. Main distinctive features can be—depending on the product's context—the user's goals concerning the target system, the technical or use-oriented level of experience or the organizational role captured by the users [5, 8, 9]. Latter shows the tight interplay between role descriptions and user classes. Class descriptions can reach from simple, often assumption-based category depictions to detailed, well-grounded *user profiles* [10].

However, user classes remain abstract and offer just a rough differentiation telling little about the real user needs. More vivid are user descriptions that depict a single concrete, fictive person as a representative for a specific group of users. Popular methods are different types of *personas* [11]. They consist of detailed, mainly narrative descriptions of fictive characters often based on extensive studies and data of real people [5]. The potential and handling of personas has been extensively described in literature [12].

Another form of modeling is the *archetype* or—with rather negative connotation—the *stereotype*. Here, the archetype shall be understood as a denomination for a putative precisely defined class of persons with specific characteristics that is—at least along general lines—inter-individually valid. The delimitation to user classes and to concrete user descriptions is smooth and often unclear. Archetypes represent, like user classes, a type of users, though these are more precisely and demonstratively defined. They are suited to mediate specific characters of a category (e.g. "the shuttling business man"), but also tend to caricature (e.g. "the computer nerd") resulting in a limited value of these descriptions [5]. However, an advantage of archetypes is their simple creation since only few or even no user data has to be collected [13, 14].

Furthermore, so-called *extreme characters* are described as narrative, extreme personalities with exaggerated emotional attitudes [15]. Aim here is to foster the design creativity by deviating from only regarding prototypical characters of a specific target group.

User models can only unfold their entire potential when they are integrated into the ongoing development process during and after their creation and refinement; this means they actually have to be utilized. Especially personas seem to be helpful. Process models like the goal-directed design [11, 16] or the concept development process for requirements engineering [17] regard user descriptions within the development process and pursue the idea of not letting the models become fixed and more or less dead artifacts after their creation. Instead, they should permanently be present, accompany and support the development process together with other usability methods and also evolve and be enhanced themselves during the design and implementation phases of product development.

The required efforts often stay unattended since practical application of usability engineering, in general, is challenging. Especially, there are no specific tools supporting user analysis and the continuous consideration of user needs throughout all software design and development activities. By providing suited instruments for user analysis and user modeling and fostering their explicit integration into all phases of software development we like to contribute to a more user-centered development of interactive systems.

2 Challenges of Usability Engineering in Practice

Next to methods for user analysis and user modeling, there exists a huge set of usability engineering procedures that primarily focus on other aspects of the relevant context; for example the analysis of tasks or organizational structures. There are also descriptions of comprehensive usability engineering processes offering combinations of methods for the analysis of the entire context of use. But most of those process descriptions are directed at usability experts and the instructions stay quite theoretical [4]. Within authentic project contexts, we see three main obstacles concerning the practical application and integration of usability engineering methods: a *low level of guidance* in method application, *insufficient flexibility* of methods and *lack of awareness* of developed results within the project team.

The first challenge, *the low level of guidance*, refers to the question, how software analysts, designers, programmers and testers who are not specially trained in usability engineering can be enabled or supported to apply methods of usability engineering and user analysis. This often starts with a lack of understanding of the methods themselves. But as well with regard to rather low threshold methods, like for example user models, the team will be confronted with the difficulty of finding a reasonable starting point or the challenge of a meaningful adaption of the methods chosen for the particular project or domain [3, 18].

The second challenge addresses insufficient *flexibility* and the open question of how usability methods can be integrated into existing processes. Companies are often unable or unwilling to change their development processes. Others seem to be quite helpless, how to change existing development workflows in favor of usability methods or how to see interfaces between usability engineering activities and standard software engineering procedures [3]. *Fading results* are a related problem, meaning that the potentially expensive application of usability engineering methods becomes worthless in later phases of the process because of deficient integration of the results in ongoing or following development phases. This is related to the issue that the results of the analyses would need to be merged and cross-referenced to provide a coherent overview of the project and problem scope. A set of single, self-contained methods without bringing the results together cannot reveal all relevant aspects.

The third challenge, the *lack of awareness*, stresses the point, that especially small or medium sized enterprises do not have the resources to hire their own usability experts [1]. But even if they have a team or person responsible for this, the efforts become useless if the results are not communicated to all other project and team members or if they are not accepted by them. Especially user analysis and user modeling are still rarely interwoven with standard system development processes. In practice, even when flexible and low-threshold methods like personas have been applied, the outcome too often will be ignored, neglected or simply gets lost during the further process since possibilities for further utilization are not recognized by the team [3].

We see *tool support* for project and team specific usability engineering methods, their combination, that means the *aggregation of analysis results* and support for the utilization of developed results throughout the entire development process as a strategy to overcome these problems addressed above. Seeing user models as quite valuable usability engineering artifact, we hope to foster the development of usable software by tool support for all steps of *user analysis seamlessly integrated* into the software development process chain.

2.1 Tool Support

Stronger tool support and the provision of usable instruments that are flexibly adaptable to existing workflows can offer the missing guidance in method application. Appropriate tooling can offer access and starting points and thereby motivate to try out new usability engineering activities. These tools have to mediate a suited framework for single closed methods and activities, so they can be easily applied with only little extra effort. On the other hand, they should offer interfaces to other areas of analyses to foster integrated considerations of the entire specific context of use.

2.2 Integration and Aggregation of Developed Results

The integrated consideration of all developed results is our second point in meeting the usability engineering challenges. Ideally, proposed tools should not only be used as stand-alone instruments. Rather, the usage of tools should be used for the aggregation of developed results and their integration in all process steps. Results should be combinable and re-usable whereby the linking of methods (resp. tools) should not follow strict process chains but stay flexible to project requirements.

2.3 Seamless User Analysis with Integrated User Models

As stated, within our research, we pay special attention on user analysis and user modeling methods. Concerning this area of usability engineering, the integration of developed results should be implemented in such a way that user analysis artifacts and the consideration of user needs become steady parts of software development. User analysis must no longer be one specific method that will be performed at one point within the process but must become a continuous activity that is seamlessly integrated into all project steps. Since user models can be used as stand-alone artifacts, they can easily be integrated into other kinds of analyses and be consulted for further usability engineering efforts. This enriches all activities and fosters the continuous awareness for the target users of the product to develop throughout all project phases.

The above mentioned three aspects can be assembled to an approach in which stronger tooling assisted by flexible instruments shall overcome first hurdles of performing usability engineering and foster more user-centered design in practice. These instruments should be combined to support comprehensive and broad analyses. Especially, we like to benefit from the characteristics of user models as a method that is not too complex, flexible in utilization and combination, whose artifacts can always be enhanced and adjusted and can particular express product requirements lively and in a way all project members can understand. By introducing the term *Integrated User Models*, we stress the demand for the integration of user analysis artifacts within following analyses and all design decisions made.

To support the creation and usage of user models, there is a need on one hand for tools that offer help for the collection and evaluation of user data as well-grounded foundation for following analyses and tools for the transformation of this data into suited user models. On the other hand, there has to be a framework in which developed usability engineering artifacts can be used and re-used, enhanced and aggregated.

Such a platform should offer seamless paths through all steps of user analysis (Fig. 1): Tasks within user analysis along the development process chain begin with the collection of user data, often done in the field, as a starting point for further analyses. Next, the project team has to evaluate and transform this data collected

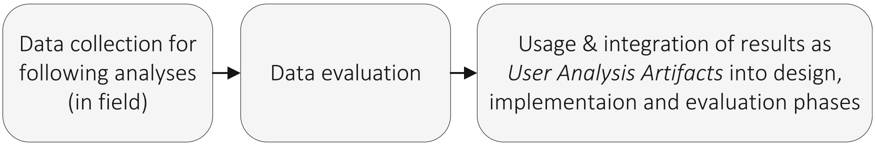


Fig. 1 Steps of comprehensive user analysis

about users into user analysis artifacts like manageable and comprehensible user models that can be reviewed and refined along the whole development process. To make use of these models and keep the rationales, relationships to other analysis results have to be built up creating a broad and consistent view of the users in their work context. Furthermore, the models and the consequences have to be communicated within the whole project team as well as to the customer for critical review and acceptance.

The Usability Engineering Repository UsER

Our Usability Engineering Repository UsER offers a platform for comprehensive and integrated user analysis [19–21]. With UsER we want to foster the practical use of a broad spectrum of usability engineering methods using a flexible approach of modular, easy to handle tools. Modeled information entities in the system can be linked together. By this, a semantic network of analysis and design objects such as *user models, tasks, artifacts, scenarios, organizational structures* and other pieces of context information can be collected and bound together into a semantic web of users, their activities and their work contexts.

Each of the UsER modules offers support for the analysis of specific aspects of the context of use. Other additional tools foster the development of usable software by supporting project management activities. The modules can be combined arbitrarily, so they stay flexible but can also be assembled to support a holistic and well-grounded user-centered design process (Fig. 2).

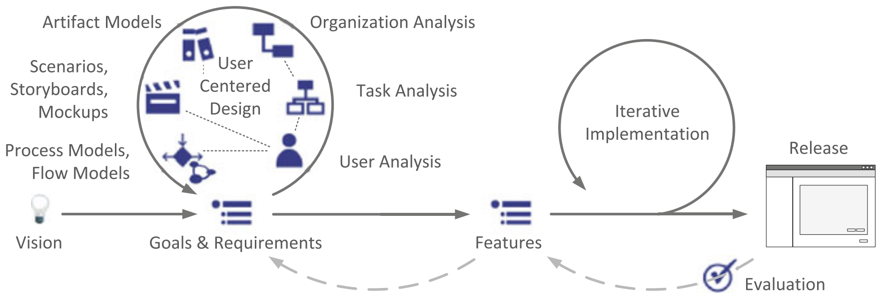


Fig. 2 Possible usability engineering process supported by UsER modules

2.4 Continuous User Analysis with UsER

Our aim to combine the idea of *Tool-Supported Usability Engineering* with the potentials of user models has already been addressed within UsER. We offer flexible instruments to assist the mentioned steps of user analysis. The *user analysis module* (Fig. 3) in UsER supports the creation and evolution of user models such as user classes, stereotypes, and personas on several levels of abstraction. Thereby it offers an instrument for *Gradual User Modeling* [22]. First, abstract classifications help to provide an overview of the users. But since they do not give a sufficiently vivid image of the target users, the refinement and differentiation of rough user models to individual user descriptions is encouraged in particular. Following a two-stage hierarchical modelling concept, within the first level, user classes can be defined in arbitrary forms and refined into kinds of archetypes continuously, for example by the definition of subclasses. The individual layer below holds descriptions that picture individual and concrete users that can be directly derived from specific user descriptions on the user class level. These functionalities are integrated within the user analysis module by graphical manipulation allowing visual modeling of the target user landscape.

The user models can be further specified by completion of user model attributes. Attribute templates offer guidance in creating for example simple user class descriptions or personas with typical attributes as found in literature. Templates stay editable and project-specific templates can be easily defined.

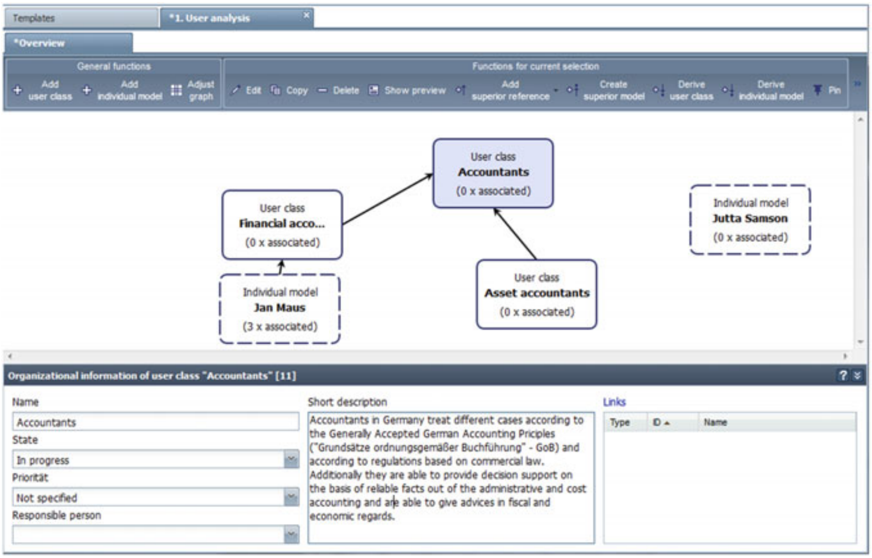


Fig. 3 The user analysis module in UsER. This screenshot shows the graphical *user landscape editor*. Additional views exist for the content-related design of single user models and for the definition of user model templates

Created user models can be explicitly integrated with other analysis and design entities. For example, they can be used as vivid actors in other UsER modules like within scenarios, as user roles in workflows, or can be referenced inside organizational charts and task structures. This is implemented by extending the respective analyses by user model icons offering quick access to the most relevant information of the modeled user or by links to user models within textual descriptions (Fig. 5). Thereby, the models become integrated components of other usability engineering artifacts and enrich the respective analyses by stronger user focus. Hence, user needs are seamlessly blended with considerations concerning the different aspects of the context of use letting those become livelier and more tangible.

One central component of UsER is the linking widget (Fig. 4). It allows the definition of arbitrary bidirectional links between two UsER entities. Additionally to the above described integration into specific modules, this general linking option enables an even stronger interweaving of user models with all other usability engineering artifacts.

Next to the user analysis module itself and the integration of created models into other UsER modules, we strengthen user focus by additional features: by integrating modeled users into core system components, too, we increase their presence and, by that, strengthen the awareness about them among the entire project team. One important feature is the pinning of selected user models to a permanently visible area in the project header within the UsER screen (Fig. 5). An icon represents the modeled user and offers quick access to detailed information. By this, the

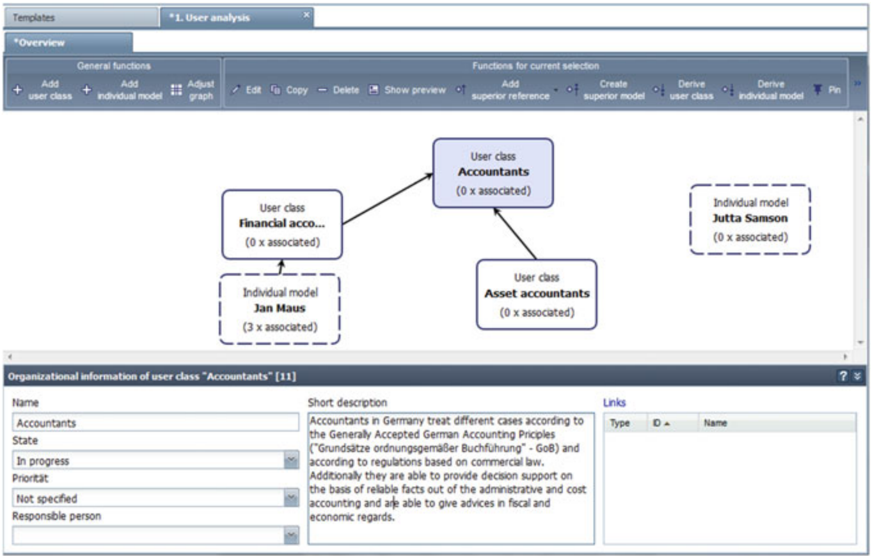


Fig. 4 This screenshot of UsER shows the opened requirements module next to the module management panel (*on the left*). The detail area of each module includes the linking widget (*on the bottom right*) offering the functionality to define links between UsER entities

Fig. 5 The pin function in UsER (*left*) and a reference to a user model within a scenario description (*right*)

future users, their characteristics and needs are explicitly presented while working with the system UsER in all project phases. This feature can be extended by letting the model become more alive by actively communicating to the current users of the system. For example, a persona could tell how well its needs have been addressed so far by referring to the requirements defined within the UsER requirements module (Fig. 4).

To address the first steps of user analysis, we plan stronger support for the collection and management of user data and to enhance the logical connection between data and user model. In student projects, first concepts for a module for the collection of empirical user data are developed. Such a module should support the planning and execution of user research activities in the field such as interviews or end user observations. Furthermore, it shall enable the input and evaluation of collected data and observations into the system UsER. As independent UsER entities those shall act as a foundation for further analyses.

We will undertake further efforts into semantic enrichment of links between UsER entities. By adding semantic annotations to links, we want to achieve automatic evaluation and depiction of how well the project progresses and matures in respect to usability. This also relates to a stronger coupling between user needs and the requirements of the product to develop. The UsER requirements module (Fig. 4) offers the functionality to define and to manage system requirements. By relating them and their priority to the needs of relevant user models and by incorporating user goals as additional requirements type, we achieve a stronger coupling between user-centered usability engineering and requirements engineering.

3 Conclusions

This contribution discusses stronger *tooling for usability engineering methods* as a promising approach to overcome main challenges of practical application of *user-centered design activities*. Tool support can provide *guidance* in the application of usability engineering methods in form of flexible instruments that are easy to use and foster the integration of usability engineering methods into existing software development processes.

We combine the idea of *Tool-Supported Usability Engineering* with the potential of *user models* as usability engineering artifacts that can be integrated with other analyses entities in many ways.

Our *Usability Engineering Repository UsER* offers a platform for a large spectrum of usability engineering tools and their flexible combination with various interfaces between all artifacts. This fosters the comprehensive understanding of the context of use. In particular, we aim to use the benefits of user models within the development process. In UsER we motivate and support the creation and elaboration of user models and let them become self-evident and lively project entities that are always present and can be evolved, reused and integrated into other aspects of system and work analysis. Therefore, user modeling will not stay an isolated and academic method anymore. The development results become traceable and omnipresent in respect to human-centered system design.

With the concept of *Integrated User Models* incorporated into a Usability Engineering Repository for flexible usability engineering tools we offer an instrument for *Seamless User Analysis* with continuous focus on user needs throughout all phases of software development.

References

1. Vukelja, L., Müller, L., Opwis, K.: Are engineers condemned to design? A survey on software engineering and UI design in Switzerland. In: Baranauskas, M.C.C., Palanque, P.A., Abascal, J., Barbosa, S.D.J. (eds.) Human-Computer-Interaction—INTERACT, Part II., LNCS, vol. 4663, pp. 555–568. Springer, Berlin (2007)
2. Marcus, A.: User interface design's return on investment: examples and statistics. Chapter 2. In: Bias, R., Mayhew, D. (eds.) Cost-Justifying Usability. An Update for the Internet Age (2nd ed.), pp. 17–39. Elsevier, San Francisco (2005)

3. Metzker, E., Reiterer, H.: Use and reuse of HCI knowledge in the software development lifecycle—existing approaches and what developers think. In: Hammond, J., Gross, T., Wesson, J (eds.) Usability: Gaining a Competitive Edge. IFIP World Computer Congress 2002. Kluwer Academic Publishers (2002)
4. Richter, M., Flückiger, M.D.: Usability Engineering kompakt. Springer, Berlin (2013)
5. Pruitt, J., Adlin, T.: The Persona Lifecycle: Keeping People in Mind throughout Product Design. Morgan Kaufmann, San Francisco (2006)
6. Constantine, L.: Users, roles, and personas. In: Pruitt, J., Adlin, T. (eds.) The Persona Lifecycle, pp. 499–519. Morgan Kaufmann/Elsevier, Amsterdam (2006)
7. Wang, X.: Personas in the User Interface Design (2011)
8. Adlin, T., Pruitt, L.: The Essential Persona Lifecycle: Your Guide to Building and Using Personas. Morgan Kaufmann Publishers Inc., San Francisco (2010)
9. Herczeg, M.: Software-Ergonomie. Theorien, Modelle und Kriterien für gebrauchstaugli-che interaktive Computersysteme (3rd ed.). Oldenbourg, München (2009)
10. Helander, M.G., Landauer, T.K., Prabhu, P.V.: Handbook of Human-Computer Interaction, 2nd edn. Elsevier Science Inc., New York (1997)
11. Cooper, A.: The Inmates are Running the Asylum. SAMS, Indianapolis (1999)
12. Nielsen, L.: Personas—User Focused Design. Springer, London (2013)
13. Grudin, J.: Why personas work: the psychological evidence. In: Pruitt, J., Adlin, T. (eds.) The Persona Lifecycle, pp. 643–663. Morgan Kaufmann/Elsevier, Amsterdam (2006)
14. Turner, P., Turner, S.: Is stereotyping inevitable when designing with personas? Des. Stud. **32** (1), 30–44 (2011)
15. Djajadiningrat, J.P., Gaver, W., Fres, J.W.: Interaction relabelling and extreme characters: methods for exploring aesthetic interactions. In: Proceedings of the 3rd Conference on De-signing Interactive Systems: Processes, Practices, Methods, and Techniques, pp. 66–71. ACM, New York (2000)
16. Cooper, A., Reimann, R., Cronin, D.: About Face 3: The Essentials of Interaction Design, 3rd edn. Wiley Publishing, Indianapolis (2007)
17. Sim, W., Brouse, P.: Empowering requirements engineering activities with personas. Procedia Comput. Sci. **28**, 237–246 (2014)
18. Mayhew, D.J.: The Usability Engineering Lifecycle: A Practitioner's Handbook for User Interface Design. Morgan Kaufmann, San Francisco (1999)
19. Herczeg, M., Kammler, M., Mentler, T., Roenspieß, A.: The usability engineering repository UsER for the development of task- and event-based human-machine-interfaces. In: Narayanan, S. (eds.) 12th IFAC, IFIP, IFORS, IEA Symposium on Analysis, Design, and Evaluation of Human-Machine Systems. International Federation of Automatic Control, pp. 483–490. Las Vegas (2013)
20. Kammler, M., Roenspieß, A., Herczeg, M.: UsER: Ein modulares usability-engineering-repository. In: Mensch & Computer 2012: interaktiv informiert—allgegenwärtig und all-umfassend, pp. 333–336. Oldenbourg, Munich (2012)
21. Paul, M., Roenspieß, A., Herczeg, M.: UsER—Ein prozessorientiertes Entwicklungssystem für Usability-Engineering. In: Boll, S., Maaß, S., Malaka, R. (eds.) Mensch and Computer 2013: Interaktive Vielfalt, pp. 181–190. Oldenbourg, Munich (2013)
22. Hüttig A., Herczeg, M.: Tool-based gradual user modeling for usability engineering. In: ECCE 2015 Proceedings of the European Conference on Cognitive Ergonomics (2015)

The meCUE Questionnaire: A Modular Tool for Measuring User Experience

Michael Minge, Manfred Thüring, Ingmar Wagner and Carina V. Kuhr

Abstract Nowadays, a satisfying user experience is the goal of any user-centered design activity and the key to success for any technical device. User experience (UX) is a holistic concept that emphasizes the importance of subjective appraisals, feelings and motivational tendencies before, during and after interacting with a technical product. It includes numerous aspects, such as usability, aesthetics, social communication of personal values, emotional stimulation and motivational support for using and reusing the product. Based on a comprehensive framework of UX, the Components model of User Experience (CUE) by Thüring and Mahlke (Int J Psychol 42:253–264, 2007, [1]), a new questionnaire for a standardized measurement of UX was developed, the meCUE questionnaire. This questionnaire consists of four separately validated modules which refer to instrumental and non-instrumental product perceptions, user emotions, consequences of usage, and an overall judgment of attractiveness. The construction of the questionnaire was based on two online data collections, in which n = 238 subjects participated respectively. Two laboratory experiments and a further online survey were conducted for determining the reliability and the validity of the questionnaire. Results support the assumption that both, the internal consistency of the constructed scales as well as their discriminative, criterion-related and construct validity are highly acceptable. Therefore, meCUE is a valuable and economic instrument for measuring key aspects of UX providing a promising alternative to existing questionnaires.

M. Minge (✉) · M. Thüring · I. Wagner · C.V. Kuhr
Department of Cognitive Psychology and Ergonomics,
Technische Universität Berlin, Sekr. MAR 3-2,
Marchstraße 23, 10587 Berlin, Germany
e-mail: Minge@tu-berlin.de

M. Thüring
e-mail: ring@tu-berlin.de

I. Wagner
e-mail: Ingmar.Wagner@zoho.com

C.V. Kuhr
e-mail: C.V.Kuhr@gmail.com

M. Soares et al. (eds.), *Advances in Ergonomics Modeling, Usability & Special Populations*, Advances in Intelligent Systems and Computing 486,
DOI 10.1007/978-3-319-41685-4_11

Keywords User experience · Usability · User emotions · Aesthetics · Intention of use · Evaluation · Questionnaire

1 Introduction

These days, user experience (UX) is regarded as a key factor for the success of almost any product. Developers and designers who strive to create positive experiences while avoiding any negative impressions depend on a variety of data which represent the user's perspective on their product. For collecting such data, a number of questionnaires have been developed which capture different aspects of UX. For example, AttrakDiff [2] and the User Experience Questionnaire (UEQ) [3] measure product perceptions on diverse dimensions which address pragmatic and hedonic qualities. For assessing the emotional component of experience, verbal (e.g. PANAS [4]) as well as non-verbal instruments (e.g. SAM [5], PrEmo [6], LEM-Tool [7]) are available.

All these questionnaires measure the UX components they focus upon in a valid and reliable way. However, no instrument so far assesses all these components together. Instead, questionnaires with different scales, formats and instructions must be employed in combination to achieve a comprehensive view on the UX of a product. Such a compilation of methods can be rather confusing for test persons and requires additional effort on behalf of the researcher who must select the most suitable tests and aggregate data from different scales.

To cope with this problem, a new questionnaire was developed that addresses all key components of UX in a unified way. Since it is based on an analytic framework, the Components model of User Experience (CUE) by Thüring and Mahlke [1], the questionnaire is called meCUE (modular evaluation of key Components of User Experience). The CUE model integrates a number of theories and approaches and

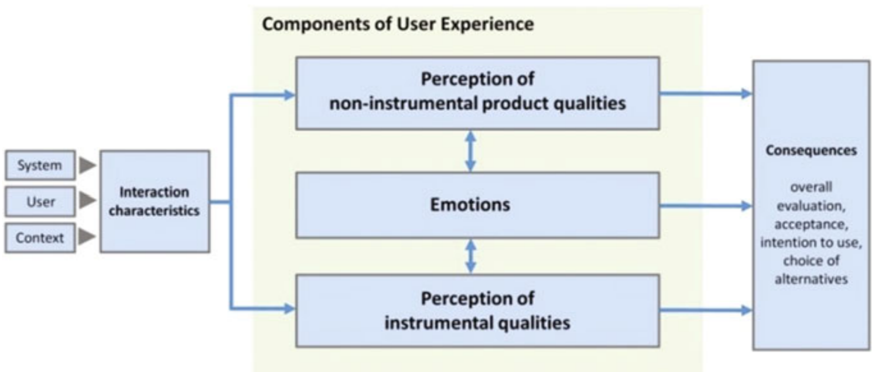


Fig. 1 Components of user experience (CUE model) by Thüring and Mahlke [1]

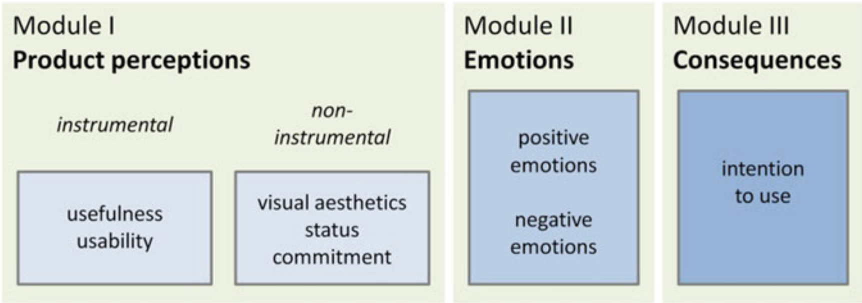


Fig. 2 Structure of meCUE derived from the CUE model

distinguishes between the perception of instrumental and non-instrumental qualities (see Fig. 1). Furthermore, it assumes that emotions mediate between both types of perceptions and influence the consequences of usage (e.g. overall judgment, acceptance, and intention to use).

The structure of meCUE corresponds to the components and subcomponents that are specified by the CUE model (see Fig. 2). In order to provide a comprehensive and flexible alternative to existing questionnaires, three central modules were constructed and validated separately. Due to its modular configuration, the new questionnaire can be easily adapted to specific research goals by simply choosing those modules which are required. The modules of the intended structure are presented in Fig. 2. Module one addresses product perceptions in terms of instrumental and non-instrumental qualities. According to Davis [8] instrumental qualities can be divided into perceived usefulness and perceived usability. For non-instrumental qualities, visual aesthetics, status and commitment serve as sub-constructs. Module two captures positive and negative emotions and module three assesses the consequences of usage with respect to intentions of future use.

2 Item Selection

An initial pool of 67 items was generated for the modules in two brainstorming sessions, each lasting about two hours. For each dimension, six to eight items were created which were particularly characteristic for the corresponding aspect of user experience. The search for adequate items was supported by a comprehensive review of existing questionnaires measuring usability or user experience. All generated items had the format of statements and were combined with a seven-point Likert scale to capture the level of agreement. The following response labels were used: “strongly disagree”, “disagree”, “somewhat disagree”, “neither agree nor disagree”, “somewhat agree”, “agree”, “strongly agree” [8].

The item selection was based on two data collections which were conducted with an online version of the item pool. Participants were asked to evaluate an interactive product that they used daily. While the first survey was performed to select items of

Table 1 Characteristics of two samples that were used in the design phase of the questionnaire

	First sample	Second sample
Number of participants (*female/male*)	n = 238 (127/111)	n = 238 (134/104)
Mean age (*Age range*)	28.6 (19–61)	28.5 (17–65)
Evaluated products (frequency)		
Mobile phone	100	106
Laptop/computer	75	75
Digital camera/mobile audio player	16	23
Coffee machine	19	8
Washing machine	13	16
TV	12	0
Mobile application/software	3	10

module one (‘product perceptions’), the second one served to select items of module two (‘emotions’) and three (‘consequences of usage’). Table 1 shows the characteristics of the two samples.

The CUE model assumes that only instrumental and non-instrumental qualities represent independent dimensions, while appraisals, emotions and consequences may be correlated. For this reason three separate variance maximizing principle component analyses were carried out with the items of the three modules.

On the basis of the Minimum-Average-Partial-Test by Velicer [9] the analysis of items measuring ‘product perceptions’ revealed the expected number of five independent components. The initial item pool could explain 69.9 % of the total variance. According to the theoretical assumptions, these factors were named as: (1) usefulness, (2) usability, (3) visual aesthetics, (4) status and (5) commitment. Considering the item-specific parameters (selectivity, distribution of difficulty and communalities) three items with high factor loadings were selected for each of the five dimensions.

The variance maximizing factor analysis of the items measuring ‘user emotions’ revealed two independent main components for experiencing positive and negative emotions. These factors could explain 57.4 % of the total variance of the initial item pool. Both for the positive and for the negative dimension, six items with high factor loadings (>0.4) were selected, respectively. One half of these items represent emotions that are associated with low arousal and one half those that are associated with high arousal. The third factor analysis showed that two dimensions were essential for subjective ‘consequences of use’, instead of one dimension as originally assumed (see Fig. 2). Both factors explained 63.5 % of the total variance. Based on the pattern matrix, the labels ‘product loyalty’ and ‘intention to use’ were assigned to them ex post and module three was extended accordingly (see Fig. 9). At the end of the item selection, the questionnaire consisted of 33 items measuring nine dimensions which were clustered in three modules. For determining the internal consistency and the validity of the questionnaire, two experiments and a further online survey were conducted which are summarized in the following sections.

3 Testing the Internal Consistency and Examination of Validity

The first experiment aimed at determining the internal consistency and the validity of the questionnaire. 67 participants (*Mean age*: 28.8 years) completed typical tasks with three different interactive products (mobile audio player, text-editing software and one's own mobile phone). Products were presented in counterbalanced order. After each interaction, subjects evaluated the product with six questionnaires: AttrakDiff [2], UEQ [3], PANAS [4], Self-Assessment-Manikin [5], visual aesthetics questionnaire [10] and the newly developed meCUE. The questionnaires were presented in random order. Each session lasted about 50 min. Participants were paid 10 Euro.

The experiment generated 201 data records which were analyzed by three principal component analyses. Results show that the assumed factorial structure of all modules could be reliably confirmed (see Table 2). The proportion of variance that is explained by the factors is even higher than in the design phase, indicating that suitable items had been selected from the pool. In the present study, we observed a higher range of variance in the ratings, due to the fact that participants

Table 2 Proportions of explained variance and Cronbach's alpha for all scales

Scale	Proportions of explained variance	Cronbach's alpha
Module I "Product perceptions"		
Usefulness	15.1	0.83
Usability	16.0	0.89
Visual aesthetics	18.1	0.89
Social identity: status	15.8	0.83
Social identity: commitment	16.1	0.86
Total	**81.1**	
Module II "User emotions"		
Positive emotions	39.5	0.94
Negative emotions	34.8	0.92
Total	**74.3**	
Module III: "Consequences of usage"		
Product loyalty	38.3	0.86
Intention to use	35.8	0.76
Total	**74.1**	

also rated products that they did not use in daily life. Cronbach's alpha for each scale is listed in Table 2. All values indicate that the internal consistency of the scales is acceptable (0.8 > α > 0.7), good (0.9 > α > 0.8) or even excellent (1 > α > 0.9).

To assess the validity of the new questionnaire, correlations between the scales of meCUE and corresponding dimensions of the other questionnaires were calculated (n = 201). Since relationships were expected between ratings of pragmatic quality and objective usability criteria, correlations between scale values and the number of completed tasks while working with the text-editing software were determined (n = 67).

Strong correlations were expected between the two instrumental scales 'usefulness' as well as 'usability' and the respective dimensions of UEQ and AttrakDiff. Smaller correlations should be observed between the scales measuring instrumental qualities and non-instrumental dimensions, including visual aesthetics. The correlations are shown in Table 3. Due to the large sample (n = 201), even small values are significant. As expected, strong correlations (r > 0.7) were observed between 'usability' and 'pragmatic quality' (AttrakDiff) as well as 'perspicuity' and 'dependability' (UEQ). 'Classical' and 'expressive aesthetics' are correlated with the 'visual aesthetics' scale of meCUE ($r \geq 0.7$). The number of completed tasks with the text-editing software is significantly correlated with the two instrumental scales only (n = 67).

Table 3 Correlations between meCUE's product perceptions and other criteria

		Scales of the meCUE questionnaire				
		Usefulness	Usability	Visual aesthetics	Status	Commitment
Correlations between meCUE and other questionnaires						
AttrakDiff	Pragmatic quality	0.64**	**0.87****	0.57**	0.46**	0.53**
	Identification	0.62**	0.52**	0.67**	0.51**	0.58**
	Stimulation	0.40**	0.37**	**0.72****	0.51**	0.50**
	Attractiveness	0.67**	0.68**	**0.77****	0.55**	0.64**
UEQ	Efficiency	0.61**	0.65**	0.55**	0.35**	0.44**
	Perspicuity	0.62**	**0.85****	0.48**	0.37**	0.44**
	Dependability	0.69**	**0.73****	0.54**	0.43**	0.54**
	Stimulation	0.62**	0.61**	**0.72****	0.54**	0.58**
	Novelty	0.36**	0.40**	0.67**	0.48**	0.45**
	Attractiveness	0.68**	**0.70****	**0.74****	0.54**	0.60**
Visual aesthetics	Classical aesthetics	0.46**	0.52**	**0.70****	0.42**	0.43**
	Expressive aesthetics	0.43**	0.40**	**0.75****	0.56**	0.51**
Correlations between meCUE and external criterion						
Number of completed tasks		**0.32****	**0.34****	0.03	0.04	0.14

**$p < 0.01$

Table 4 Correlations between scales measuring emotions and consequences

		Scales of the meCUE questionnaire			
		Positive emotions	Negative emotions	Product loyalty	Intention to use
Correlations between meCUE and other questionnaires					
PANAS	Positive affect	**0.51****	−0.39**	**0.53****	**0.54****
	Negative affect	−0.26*	**0.63****	−0.42**	−0.39**
SAM	Arousal	−0.22*	0.35**	−0.25*	−0.25*
	Valence	**0.66****	**−0.65****	**0.69****	**0.67****
Correlations between meCUE and external criterion					
Number of completed tasks		0.16	−0.22	0.28*	0.21

*$p > 0.05$
**$p < 0.01$

With respect to emotions, strong correlations were obtained between the dimensions for positive affect (resp. emotions) of PANAS and meCUE as well as between the dimensions for negative affect (resp. emotions). Moreover, the valence ratings captured by the Self-Assessment Manikin (SAM) highly correlated with the emotion scales of meCUE (see Table 4). Correlations between SAM's arousal scale and the meCUE scales are low ($r = -0.22$ and $r = 0.35$). This result was expected since one half of the meCUE items represent emotions with high arousal and one half items with low arousal. Table 4 also shows relationships between consequences and emotions. For 'product loyalty' and 'intention to use' stronger correlations were found with positive affect measured by PANAS as well as with positive valence captured by SAM.

In sum, strong correlations were found between meCUE and corresponding dimensions of other questionnaires. The empirical pattern indicates that the validity of meCUE is highly acceptable. Furthermore, all scales have good internal consistency.

4 Supplement to the Questionnaire

According to the CUE model [1] an important aspect of consequences is the overall evaluation of a product. In order to assess the judgment of a product as a whole, other questionnaires like AttrakDiff and UEQ provide the subscale 'attractiveness'. In order to offer a similar opportunity, meCUE was supplemented by a further subscale. It consists of a single semantic differential with the bipolar pair "bad"/ "good". Its rating scale ranges from "−5" to "5" with an increment of 0.5, respectively (see Fig. 3).

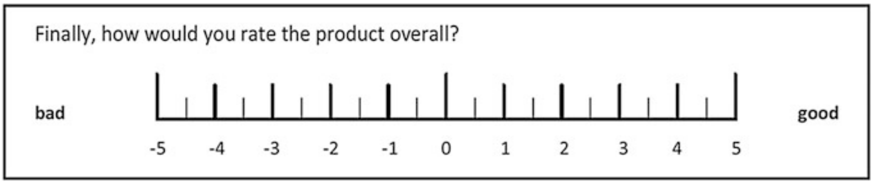


Fig. 3 Single-item for the overall judgment 'global attractiveness'

Similarly to the procedure in Chap. "Application Development for Gathering "Inexperienced UX" Data for Planning", another online study was conducted to validate the single-item 'global attractiveness'. Participants evaluated interactive products of their daily lives with AttrakDiff and meCUE. The presentation order of the questionnaires was counterbalanced. While the four modules of meCUE were assigned in a fixed order (I, II, III, IV), the respective items were assigned in a random order. 237 subjects participated in the study (*Mean age* = 29.8 years). Due to limitations of space, only the result for the overall rating is reported here (for the other findings see [11]). As expected, a strong correlation between the global judgment and the 'attractiveness' scale of AttrakDiff was found ($r = 0.559$, $p > 0.01$), supporting the assumption that the supplemented scale has an acceptable level of convergent validity.

5 Determination of Discriminative and Convergent Validity

The aim of the second experiment was to assess the validity of the final version of the meCUE questionnaire. Instead of AttrakDiff [2] and the visual aesthetics questionnaire [10] as in the first experiment, Attrak Diff-mini [12] and VisAWI-S [13] were used as internal criteria. In particular, two research questions were addressed.

1. Can meCUE reliably discriminate between applications that differ with respect to instrumental and non-instrumental qualities (discriminative validity)?
2. Are the results obtained with meCUE in line with the results obtained with other UX questionnaires (convergent validity)?

To answer these questions, an experiment was carried out in which apps for public transportation in Berlin served as test material. In order to formulate hypotheses about differences between them, the apps were pretested in an expert review. Four German usability professionals (with at least three years of practical experience rated the usability and the visual design of six public transport applications that were chosen from the iOS appstore. Based on single-item ratings for both aspects, the results were used to detect maximum and minimum differences

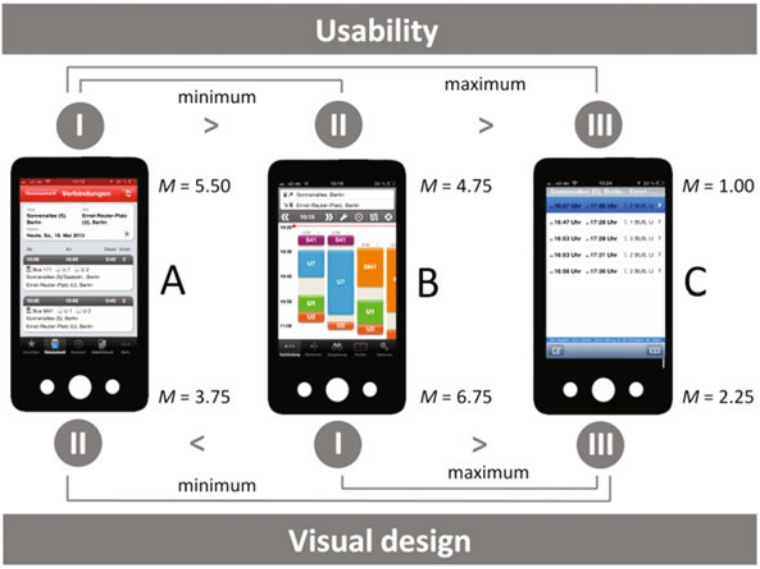


Fig. 4 Screenshots and results of the experts' ratings for the three public transport apps A, B, and C used in the main study. Latin numerals represent the ranks of the apps with respect to usability and visual design ratings, Arabian numbers show the corresponding means

between the apps. Figure 4 displays the mean scores of the single-items for the three apps that were selected for the main study. Results show that the versions A and C differed greatly with regard to usability, but only little with regard to visual design. Minimal differences in usability were observed between versions A and B, highest differences in visual design between B and C. The corresponding rank order of the apps with respect to usability was A > B > C and with respect to visual design B > A > C. If the meCUE questionnaire measures product perceptions validly it should capture these differences and rank orders in tests with users of the applications.

Based on a one-factorial within-subject design, 24 participants (Mean age = 26.1 years) accomplished a user test that consisted of a series of tasks with all apps. The order of the apps was counterbalanced over all participants. After each app, users were asked to evaluate the interaction with five questionnaires: meCUE, AttrakDiff-mini [12], UEQ [3], PANAS [4] and VisAWI-S [13].

Discriminative Validity

To answer the first research question, meCUE ratings of all instrumental and non-instrumental product qualities were analyzed by a oneway MANOVA with *Application* (Version A, B, or C) as within-subjects factor. The analysis revealed significant main effects of *Application* on all dependent variables. Subsequently, post hoc pairwise comparisons were conducted. The *p*-values of all comparisons were Bonferroni adjusted. Mean scores and significant differences are displayed in Fig. 5.

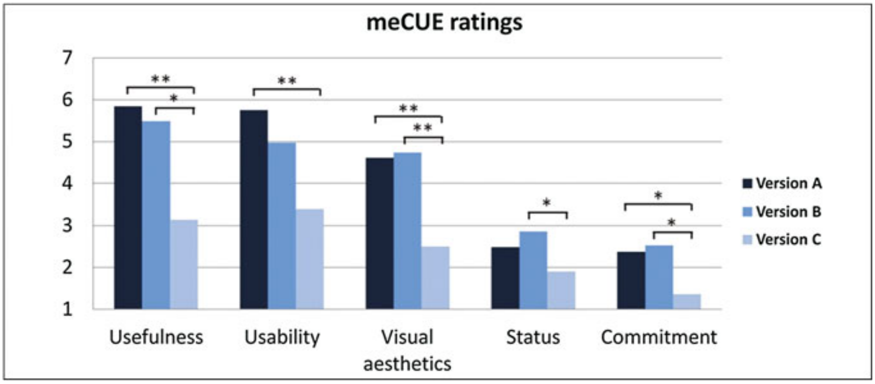


Fig. 5 Mean scores of the apps for meCUE's instrumental and non-instrumental product perceptions and significant differences between them. *$p < 0.05$; **$p < 0.01$

With respect to rank orders, the users' mean ratings show patterns that are highly compatible with those of the experts, i.e., A > B > C for the two instrumental dimension and B > A > C for visual aesthetics. As expected, not all differences between the respective means of the ranks were significant.

Usefulness and usability reached their highest value for version A and their lowest value for version C. Significant differences on these dimensions were obtained between version A and version C, but not between A and B. This pattern corresponds nicely to the experts' judgments where the usability difference was maximal between A and C and minimal between A and B.

The best visual aesthetics rating was obtained for version B and the worst one for version C. Both versions, A as well as B, were significantly different from version C. In comparison to the experts' judgments, a significant difference between B and C was to be expected, but the difference between A and C was larger than anticipated.

Ratings on the additional meCUE subscales status and commitment were comparatively low for all three apps. This is not surprising since an app for public transportation is unlikely to influence the perceived status of its owner very much, and the usage was too short and too artificial to establish a distinct bond between users and apps. Nevertheless, some significant differences between the three versions were found (see Fig. 5).

Convergent Validity

To answer the second research question, the values of the different questionnaires were standardized by a z-transformation. Thus the means for their subscales can be descriptively compared between versions A, B, and C (see Fig. 6). Additionally, correlations were calculated between corresponding subscales of the questionnaires.

As Fig. 6 shows, version A scored highest on all subscales measuring instrumental qualities while version C showed lowest scores. MeCUE's usability ratings were highly correlated with 'pragmatic quality' of AttrakDiff ($r = 0.900$, $p > 0.001$)

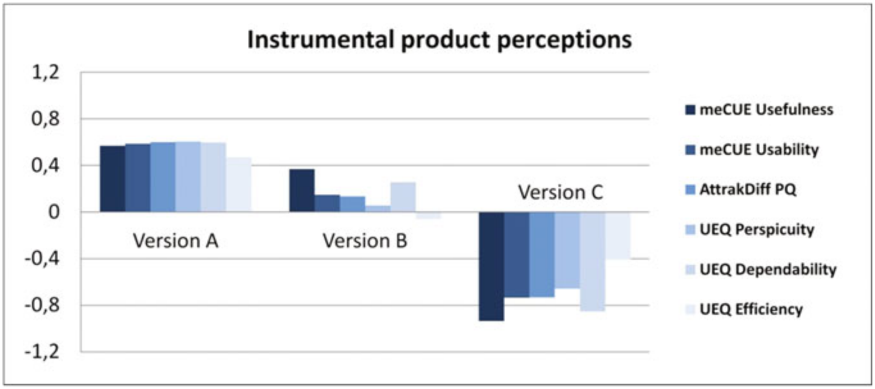


Fig. 6 Mean scores for instrumental product perceptions. All values are standardized by z-transformation

and the subscales of UEQ ($r = 0.855$, $p > 0.001$ for perspicuity, $r = 0.781$, $p > 0.001$ for dependability, and $r = 0.903$, $p > 0.001$ for efficiency).

For visual aesthetics, the meCUE ratings exhibit a pattern similar to that of the VisAWI-S (see Fig. 7). The scores of both questionnaires are significantly correlated ($r = 0.881$, $p > 0.001$). Moreover, meCUE's ratings of global attractiveness correlate significantly with the dimension 'attractiveness' of AttrakDiff-mini ($r = 0.919$, $p > 0.001$) and UEQ ($r = 0.887$, $p > 0.001$). This result is in line with the relationship between the meCUE single-item and the subscale 'attractiveness' of AttrakDiff (see Chap. "Analysis of Back Forces While Sitting Down, Seated, and Rising From a Stationary Chair in Subjects Weighing 136 to 186 kg").

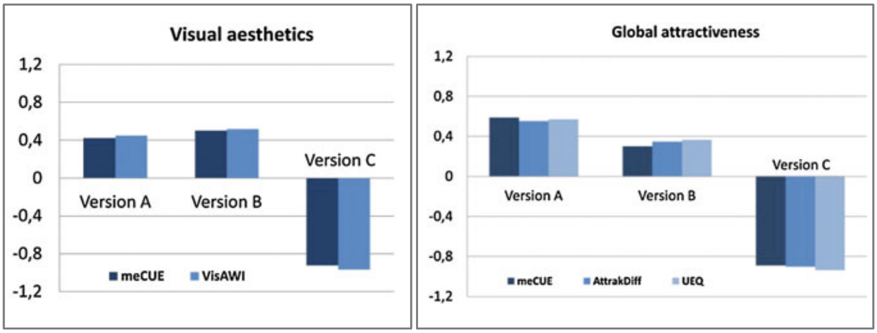


Fig. 7 Mean scores for visual aesthetics (*left*) and global attractiveness (*right*). All values are standardized by z-transformation

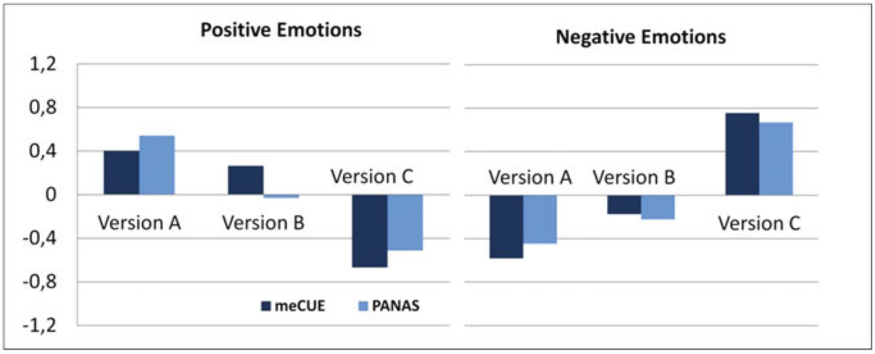


Fig. 8 Mean scores for positive (*left*) and negative emotions (*right*). Values are z-transformed

Similar constellations of means and significant correlations were also found between meCUE and PANAS, both for positive emotions ($r = 0.470$, $p > 0.001$) and negative emotions ($r = 0.717$, $p > 0.001$) (see Fig. 8).

In answer to the two research questions addressed by the experiment, the findings show that meCUE possesses both, a satisfying discriminative as well convergent validity. The questionnaire qualifies well for discriminating between different mobile apps. The results of the user test are consistent with the outcomes of the expert review conducted beforehand. Furthermore, descriptive comparisons of means and correlations indicate that the results obtained with meCUE are consistent with other validated questionnaires that measure UX or emotions.

6 Conclusion

The aim of our research was the development of a new questionnaire measuring key components of user experience in a comprehensive and unified way. Based on the CUE model, a theoretical structure of the questionnaire was deduced. This structure was validated in a series of consecutive online studies and laboratory experiments.

The final version of the questionnaire for the ‘modular evaluation of key Components of User Experience’ (meCUE) consists of four modules (including nine subdimensions and a single-item). The modules refer to ‘product perceptions’ (usefulness, usability, visual aesthetics, status, commitment), ‘user emotions’ (positive and negative emotions) and ‘consequences of usage’ (product loyalty, intention to use). The single item (module IV) enables the overall evaluation of the product (see Fig. 9).

Since the modules and the single-item were separately validated, meCUE is a flexible, adaptable, lean and effective question-naire for measuring user experience. In contrast to instruments which capture single aspects or a subset of them, meCUE addresses all central UX components together—including emotions—in a unified

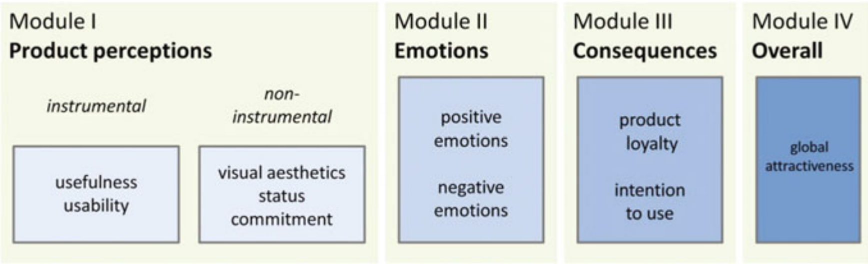


Fig. 9 Final structure of the meCUE questionnaire with four separately validated modules

format using a Likert-scale. Since the questionnaire consists of only 34 items, it is also efficient to use, requiring only between two and five minutes on average to be filled in.

As demonstrated by the reported studies, meCUE can be applied in UX surveys on all kinds of interactive systems. So far, it has been successfully deployed to measure UX for consumer products, software, diverse mobile applications as well as medical products, such as lower limb ortheses [14]. meCUE is particularly suitable for comparing different products or design options and for detecting changes of experience in the course of long-term usage.

Originally, the meCUE questionnaire was developed in German, but recently an English version has been created. To ensure a proper wording, the items were repeatedly translated back and forth by three independently working native speakers. Subsequently the English version was validated in an online study with 58 participants [15]. As the German version, the English version has a good internal consistency and reliably assesses the key components of user experience.

MeCUE is freely available under the following links: www.mecue.de/english (for the English version) and www.mecue.de (for the German version). The website also provides an Excel file that supports data collection and analysis.

Acknowledgments This research was supported by the German Research Association (DFG) as part of the Research Training Group "Prospective Engineering of Human-Technology Interaction" (GK 1013). We would like to thank Laura Riedel for her work on the studies.

References

1. Thüring, M., Mahlke, S.: Usability, aesthetics, and emotions in human-technology interaction. Int. J. Psychol. **42**(4), 253–264 (2007)
2. Hassenzahl, M., Burmester, M. & Koller, F.: Der user experience (UX) auf der Spur: Zum Einsatz von www.attrak.diff. In: Brau, H., Diefenbach, S., Hassenzahl, M., Koller, F., Peissner, M., Rose, K. (Hrsg.) Usability Professionals 2008, pp. 78–82 (2008)
3. Laugwitz, B., Schrepp, M., Held, T.: Konstruktion eines Fragebogens zur Messung der user experience von Softwareprodukten. In: Heinecke, A.M., Paul, H (Hrsg.), M&C 2006: Mensch und Computer im Strukturwandel (S. 125–134). Oldenbourg, München (2006)

4. Watson, D., Clark, A., Tellegen, A.: Development and validation of brief measure of positive and negative affect: the PANAS scales. J. Pers. Soc. Psychol. **54**(6), 1063–1070 (1988)
5. Bradley, M.M., Lang, P.J.: Measuring emotions: the self-assessment manikin and the semantic differential. J Behav. Ther. Exp Psychiatry **25**(1), 49–59 (1994)
6. Desmet, P.M.A.: Measuring emotion. Development and application of an instrument to measure emotional responses to products. In: Blythe, M.A., Monk, A.F., Overbeeke, K., Wright, P.C. (eds.) Funology: From Usability to Enjoyment, pp. 111–123. Kluwer Academic Publishers, Dordrecht (2003)
7. Capota, K., Hout, M., van & Geest, T.M., van der.: Measuring the emotional impact of websites. A study combining a dimensional and discrete emotion approach in measuring visual appeal of university websites. In: Proceedings of Designing Pleasurable Products and Interfaces Conference (2007)
8. Vagias, W.M.: Likert-type scale response anchors. Clemson International Institute for Tourism and Research Development, Department of Parks, Recreation and Tourism Management. Clemson University (2006)
9. Velicer, W.F.: Determining the number of components from the matrix of partial correlations. Psychometrika **41**, 321–327 (1976)
10. Lavie, T., Tractinsky, N.: Assessing dimensions of perceived visual aesthetics of web sites. Int. J. Hum Comput. Stud. **60**, 269–298 (2004)
11. Minge, M., Riedel, L. & Thüring, M.: Entwicklung und Validierung des meCUE Fragebogens. In: Brandenburg, E., et al. (eds.) Proceedings of 10th BWMMS, pp. 28–36 (2013)
12. Hassenzahl, M., Monk, A.: The inference of perceived usability from beauty. Hum. Comput. Interact. **25**(3), 235–260 (2010)
13. Moshagen, M., Thielsch, M.: Facets of visual aesthetics. Int. J. Hum Comput Stud. **68**(10), 689–709 (2010)
14. Doria, L., Minge, M., Riedel, L.: User-centred evaluation of lower-limb ortheses: a new approach. Dreiländertagung der Deutschen, Schweizerischen und Österreichischen Gesellschaft für Biomedizinische Technik (BMT), Graz (2013)
15. Minge, M., Wagner, I., Thüring M.: Developing and validating an English version of the meCUE questionnaire. In: International Annual Meeting of the Human Factors and Ergonomics Society 2016 (submitted)

The Hierarchical Model of Spatial Orientation Task in a Multi-module Space Station

Junpeng Guo, Guohua Jiang, Yuqing Liu and Yu Tian

Abstract Spatial orientation is a challenging task for the astronauts living inside the spacecraft that has complicated structure. To have a better understanding of the spatial orientation task inside the multi-module space station, it is necessary to find a general method to describe the orientation tasks. In this study, we proposed a hierarchical model called "LOCS" to illustrate the different types of orientation tasks. We validated the effect of this model by an experiment in the simulated multi-module space station developed by virtual reality. This model made the spatial orientation process clearer and provided a basic framework to study the related issues of orientation in the space station in the future.

Keywords Spatial orientation · Weightlessness · Virtual reality · Hierarchical model

1 Introduction

Spatial orientation is an important issue in daily life and many professional areas. In the gravitational environment, human usually integrate various sensory information for orientation, such as visual cues as well as vestibular and proprioceptive cues [1–3]. And under most circumstances, it does not need much effort to fulfill the orientation task on the earth [4–6]. Nevertheless, things could be very different when the gravity disappeared, like the situations that the astronauts meet [7]. Without gravity, there is no constant force acting on the vestibular apparatus and then human can not distinguish the up and down easily. Meanwhile, human are no longer constrained to a two-dimensional plane when the gravity is gone and can view the surrounding environment from various perspectives, especially from the perspectives that are not familiar or seldom experienced in the upright posture.

J. Guo (✉) · G. Jiang · Y. Liu · Y. Tian
National Key Laboratory of Human Factors Engineering,
China Astronaut Research and Training Center, Beijing, China
e-mail: dragonguo@126.com

M. Soares et al. (eds.), *Advances in Ergonomics Modeling, Usability & Special Populations*, Advances in Intelligent Systems and Computing 486,
DOI 10.1007/978-3-319-41685-4_12

These changes caused by the lack of gravity all contribute to the orientation difficulty in the weightless environment [8]. In addition, the spacecraft that astronauts lives in nowadays are usually connected by multiple modules and the different modules are blocked by the opaque walls, which makes it difficult for astronauts to form the overview image of the whole spacecraft as they have no opportunity to observe the complete structure at one time when floating inside the spacecraft [9].

In order to investigate the orientation methods in the weightless situation, we can first examine how we represent the spatial knowledge on the ground. Many researches about the spatial knowledge representation on the ground have been conducted [10–15]. Among them, the spatial knowledge model proposed by Sigel and White [10] is one of the most prevalent models accepted by the researchers. They name this model "LRS", which stands for "Landmark, Route, Survey". This model both discusses the spatial knowledge and its development process. According to this model, when navigating or orientating in an environment on the ground, we first extract the landmarks that are salient as well as static, orientation dependent and disconnected from one another in the environment. Landmarks can be viewed as the important but isolated spots that function as references for orientation. Then after examining the paths that connecting these isolated spots, the route knowledge develops. Route knowledge can be treated as a graph of nodes and edges that keeps expanding as more nodes and edges are added. At last, the survey knowledge is formed as the graph is complete and then people can obtain an overview knowledge of the entire environment and directly estimate the relative directions and distances between any two points. But there are also limitations of this model as it fits better for the large-scale environment such as the urban area but not so well for some small-scale environments [14, 16]. For example, people might obtain the survey knowledge in a small room almost immediately without the landmark or route knowledge. And in some cases the survey knowledge can develop quickly for the local regions but slowly for remote regions. This can be referred as the "room effect" which means that people could obtain survey knowledge of a room very quickly but relatively slowly for survey knowledge of several adjacent rooms. This effect could be explained by the "boundary theory" proposed by Mou [17, 18], which indicated that spatial ability could be damaged across the boundaries such as wall or storeys.

In order to apply the spatial knowledge representation and development model in the multi-module space station, we first need to analyze the feature of the spatial orientation task inside the space station. One main characteristic of the environment provided by the space station is the multi-module structure. Each module is a relative small-scale environment, and as described above whether the survey knowledge is obtained quickly in one single module and "room effect" exists in developing the survey knowledge of the overall space station environment remains a question. In addition, the visual verticals in the modules may appear in an inconstant way, and this means astronauts have to change the concept of up when navigating through different modules, which add to the difficulty for spatial knowledge representation and development. Another main characteristic is the multi-perspective caused by the lack of gravity. Constrained by the gravity, people almost can only yaw and translate in a two-dimensional plane. But without gravity, the degree of freedom people can move is enlarged, they can move in all of the six degrees of freedom, adding the pitching, rolling and translating upward or downward in movement. Thus, astronauts could float freely in various body orientations inside the space station and view the interior environment from different perspectives that are seldom met on the earth. This lead to the transform in the spatial representation of egocentric coordination, e.g. the objects overhead can be in the front after astronauts pitch backward. These two characteristics of the space station environment cause the prime difference in spatial knowledge representation and development in the weightlessness than on the ground. In order to make the spatial orientation process in the space station clearer and provide better preflight orientation training for astronauts, it is necessary to develop a specific model for the spatial orientation task in the weightless situation. This study investigated the spatial orientation process first and then proposed the hierarchical model for the spatial orientation task and validated the effect of the model by an experiment.

2 The Type of Spatial Orientation Task

To propose the specific model for spatial orientation task inside the multi-module space station, we first investigate the different types of spatial orientation task that the astronaut may meet when living inside the spacecraft. Generally, we classify the spatial orientation tasks inside the multi-module space station into three types.

Type I we defined is the relative simplest spatial orientation task, and it is the spatial orientation task inside one single module and without navigating. The task of this type mainly include searching objects when working or living inside one specific module or tell the direction and location of other modules when floating inside one module. It seems that this type task might need not much effort to fulfill, as one single module of the space station cannot be too large and no navigation is needed. However, in the weightlessness, astronauts could float in various body orientation, it is very possible that they only keep a clear image of the spatial relationship of the objects inside one module or all the modules connected in the space station from one or a few perspectives (namely from the perspective in the upright posture or several other particular postures). When they float in the unfamiliar body orientation, the egocentric representation of their surrounding environment changes and they can feel strange about the view from that perspective and need special effort to find the target object. This type of spatial orientation task may require people to do some mental rotation or perspective-taking.

The second type of spatial orientation task inside the multi-module space station is the spatial orientation task during the navigating process or imaginary navigation process (the word "imaginary" refers to think of the navigation process in mind but not need to behave physically) through several modules that have consistent visual verticals. The modules that have consistent visual verticals usually lie in one same plane, such as the International Space Station and the Virtual Space Station used by

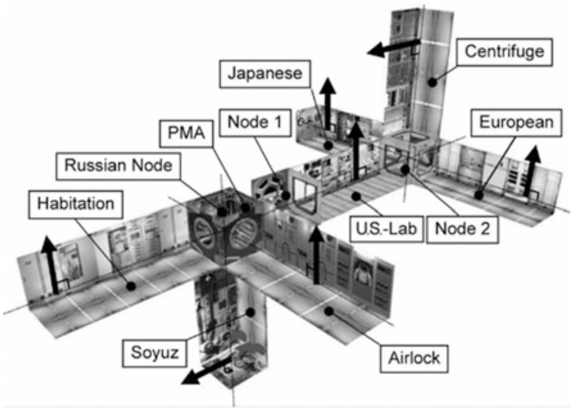


Fig. 1 The structure of the virtual space station used by the researchers in [19]. The name of each module was shown. And the *arrow* beside each module indicated the visual vertical of the module

the researchers in [19], which is shown in Fig. 1. The plane that have the most modules with the same visual verticals define the main plane. When navigating through these modules, it is a little like the navigating process on the earth, as they both on a two-dimensional plane and require people to estimate the relative direction and distance of the destination on a plane. However, although alike, these two processes can be very different. Because in the space station, when astronauts navigating from one module to another, they always need to pitch forward or backward when going across the node module as the size of the node's hatch might not large enough for astronaut to go through in an upright posture. With the extra pitch rotation, spatial orientation can be more confused than the movement only with translation and yaw. In addition, comparing to the first type task, this type task requires the orientation across the boundaries and need astronauts to possess some overall knowledge about the space station configuration in some extent.

The last type of the spatial orientation task is the spatial orientation task during the navigating process or imaginary navigation process (the word "imaginary" has the same meaning as explained in the last paragraph) through the modules that have inconsistent visual verticals. The only different between this type and the second type is that, in this type the visual verticals of the modules during the navigation process may appear in different directions. Usually, when navigating through different modules astronauts tend to adjust their body orientation in alignment with the local visual vertical, especially when the module is the destination of the navigation process. This might be the most difficult spatial orientation task. On one hand, the modules with different visual verticals usually do not lie in the same plane as shown in Fig. 1 and astronauts need to pitch forward or backward for entering into the module connected in a vertical way. On the other hand, when the visual vertical of the destination is not in alignment with the body orientation of the astronauts, the astronauts need to adjust their body orientation by rolling, which can make the representation of the spatial knowledge more complicated. Thus, we consider that the third orientation task is the most difficult one.

3 The Hierarchical Model for the Spatial Orientation Task

The three types of spatial orientation task are summarized as above. After summarizing the spatial orientation task types, we investigate what these tasks have in common so that we can find a way to describe them and this may benefit the understanding of the spatial orientation tasks in the multi-module space station as well as the orientation training for astronauts. In order to do this, we developed a simulated multi-module space station via virtual reality technique. The simulated had a similar complex structure with the International Space Station as shown in Fig. 2. People could navigate inside this simulated space station in all of the six degrees of freedom, which was similar to the situation in weightlessness. The interior environment of the simulated space station had abundant visual cues that could provide the visual vertical direction and tell the name of the module. We provided a 3D mouse for navigating inside the simulated space station and a HMD for stereoscopic vision and stronger immersive.

We reproduced the three types of spatial orientation task inside this simulated space station, and then proposed the model that could decompose the tasks. The spatial orientation task model we proposed was hierarchical and could be divided into four layers, namely "Identify location; Identify relative orientation with respect to the immediate module; Make use of the configuration knowledge; Form the survey knowledge and navigation strategy". The complete model could be used for describing the spatial orientation task in the second or third type and the Type I spatial orientation task could be explained by the first two or three layers of the model.

Image that in the second or third type of the spatial orientation task, astronauts in one module wanted to enter into another module that was not adjacent, to do this they should make a navigational plan first, namely they should find out where the target module was and think about how to get there in advance. In order to obtain this navigational plan, they should first identify which module they were located in at that moment, as it was the prerequisite for the remaining task. This is the "Identify location" process. Then the astronauts needed to identify their orientation relative to

Fig. 2 The simulated space station used in our study. It consisted of eleven modules including two node modules. The visual vertical of each module can be configured easily. In the usual configuration, the visual vertical of each module is in alignment with the "up" of the paper

the visual vertical direction of the immediate module as they might float in various body orientations, so that they could realize which reference their mental map should be aligned to later. This is the second process, namely, "Identify relative orientation with respect to the immediate module". After this, astronauts could use their configuration knowledge of the station to judge the direction of the target module and its adjacencies relative to themselves, which is the "Make use of the configuration knowledge" process. And finally after being fully aware of the relationship between themselves and the related modules, they could form an overview map and ascertain the route between the immediate and target modules, which met the goal of the orientation task. And this is the final process—"Form the overview knowledge and navigation strategy". Through these four processes (also could be name as layers), astronauts could be clear about the direction and distance between the immediate surroundings and the destination, and the route connecting them.

For the first type of the spatial orientation task, astronauts only need to identify their location first so that they can know which module they are in and what possible objects there can be. Then they need to identify their relative orientation with respect to their immediate module, and then they can understand how they should transform their egocentric coordination of the spatial representation with respect to the prototypical perspective and if they may need to use the configuration knowledge if they want to tell the direction and location of other modules.

We decomposed the three types of the spatial orientation tasks by the model we proposed. In order to make the model be expressed in a more concise way, we extracted the keyword in each layer and name the model by the initial letters in these keywords, which is "LOCS". Here, "L" is short for "Location" and stands for the first layer—"Identify the location"; "O" is short for "Orientation" and stands for the second layer—"Identify relative orientation with respect to the immediate module"; "C" is short for "Configuration" and stands for the third layer—"Make use of the configuration knowledge"; "S" is short for "survey" and stands for "Form the survey knowledge and navigation strategy". The structure of this model and its correspondence to the type of the spatial orientation tasks were illustrated in Fig. 3.

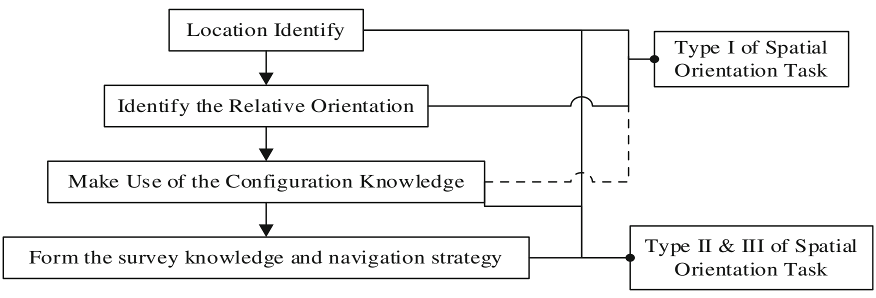


Fig. 3 The illustration of the hierarchical "LOCS" model and its correspondence to the type of the spatial orientation tasks

4 The Experimental Validation

4.1 Participants

Twelve male adults (mean age = 24.35, SD = 1.22, ranging from 21 to 26) with college-level education participated the present study. None of the participants had operated the similar spatial orientation task inside a simulated multi-module space station before the experiment.

4.2 Experimental Design

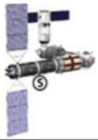
The aim of this experiment was to validate the effect of the "LOCS" model. To achieve this, the participants were divided into to two groups. One is the experimental group. In this group, the "LOCS" model was explained to the participants, and the participants were required to use the process indicated by this model during the later experiment. The other group is the control group. In this group, the participants were not taught by any special skills, and needed to explore the orientation methods by themselves in the experiment.

4.3 Experimental Procedure

All the participants needed to navigate inside the simulated multi-module space station as shown in Fig. 2. The time they used for the navigation was recorded to evaluate the performance of each participant. Before the formal experiment, all the participants were first given twenty minutes to get familiar with the simulated space station. During this process, the participants could be acquainted with the interior environment and the configuration of the simulated space station as well as the interactive method by using the 3D mouse. And the participants' self-reports showed that twenty minutes were enough for all the participants to finish this process. Then for the experimental group, the participants were taught to use the "LOCS" model to finish the navigation task by the experimenter in another twenty minutes. And the control group was also given another twenty minutes but they just explored the simulated space station by themselves.

There were eight routes in the experiment in total and all the participants needed to finish these tasks successively in the same order. In each navigation task, the initial orientation of the body in the starting module of the navigation was set differently, could be upside down or towards left and so on. The starting and target module of the navigational route was shown on the bottom right corner of the screen during the navigational process. When participants arriving in the target module, they needed to press the left key of the 3D mouse to confirm. If they

Table 1 The configurations of routes used in the navigational task

Sequence number of the route	Configuration	Sequence number of the route	Configuration
1		5	
2		6	
3		7	
4		8	

pressed the left key in a module that was not the right target module, their would get a feedback information on the screen indicating their fault and navigation time was added by 10 s. This encouraged the participants to make the confirmation only when they were certain about their choice and not to finish the task by chance. The eight navigational routes that only contained the modules navigated through by the participants were shown in Table 1.

4.4 Experimental Results

The time used by the participants of the two groups in the navigational tasks were recorded to evaluate the participants' performance. We considered that participants who used less time for navigating from the starting module to the target module had a better sense of direction, which meant better performance in the spatial orientation tasks. The average time used in each navigational route was shown in Fig. 4. And we compared the overall average time consumed in the two groups by t test, and the result showed that the experimental group used significantly less time than the control group ($t = 2.792$, $p = 0.014 < 0.05$).

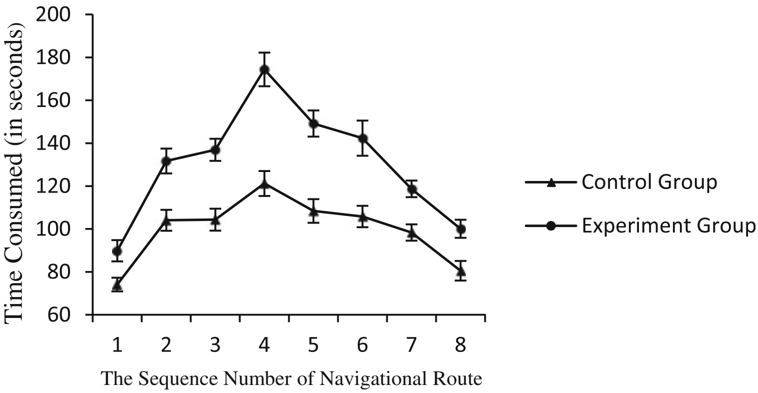


Fig. 4 The time consumed during the eight navigational tasks by the participants in the two groups in the experiment

5 Conclusion

This study investigated the spatial orientation task inside a multi-module space station. Spatial orientation in the weightlessness is an important issue for astronauts. In order to have a better methods describing and analyzing the spatial orientation tasks there, we summarized the different types of the tasks and proposed the "LOCS" model to give the description of the tasks. We validated this model by an experiment. With the help of this hierarchical model, people could make the spatial orientation process in a multi-module space station clearer. This model also provided a basic framework to study the related issues of orientation in the space station, such as optimizing the prefight virtual orientation training strategy (e.g. ensuring the astronauts be very familiar with the configuration knowledge), and analyzing the various factors that influence the spatial orientation task performance (e.g. the interior environment design might influence the first two layers in the model).

Acknowledgments This study was supported by the National Defense Basic Research Program of China (No. B1720132001). Author Junpeng Guo, Yuqing Liu were supported by the foundation of National Key Laboratory of Human Factors Engineering (No. SYFD140051807).

References

1. Ivanenko, Y.P., Grasso, R., Israel, I., Berthoz, A.: The contribution of otoliths and semicircular canals to the perception of two-dimensional passive whole-body motion in humans. J. Physiol. London **502**, 223–233 (1997)

2. Loomis, J.M., Klatzky, R.L., Golledge, R.G., Cicinelli, J.G., Pellegrino, J.W., Fry, P.: Nonvisual navigation by blind and sighted: assessment of path integration ability. J. Exp. Psychol. Gen. **122**, 73–91 (1993)
3. Rieser, J.J., Guth, D.A., Hill, E.W.: Sensitivity to perspective structure while walking without vision. Perception **15**, 173–188 (1986)
4. Pick, H.L. Jr., Rieser, J.J.: Children's cognitive mapping. In: Potegal, M. (ed.) Spatial Orientation: Development and Physiological Bases, pp. 107–128. Academic Press, New York (1982)
5. Rieser, J.J.: Access to knowledge of spatial structure at novel points of observation. J. Exp. Psychol. Learn. Mem. Cogn. **15**(6), 1157–1165 (1989)
6. Loomis, J.M., Da Silva, J.A., Fujita, N., Fukusima, S.S.: Visual space perception and visually directed action. J. Exp. Psychol. Hum. Percept. Perform. **18**, 906–922 (1992)
7. Clément, G., Reschke, M.F.: Neuroscience in Space. Springer Science & Business Media, New York (2010)
8. Oman, C.: Spatial Orientation and Navigation in Microgravity//Spatial Processing in Navigation, Imagery and Perception, pp. 209–247. Springer, US (2007)
9. Zhu, X., Liu, Y., Zhou, B., et al.: Design of a virtual training system and application of an evaluation scheme for orientation in a spacecraft cabin. In: Proceedings of the 15th International Conference on Man–Machine–Environment System Engineering, pp. 653–61. Springer, New York (2015)
10. Siegel, A.W., White, S.H.: The development of spatial representations of large-scale environments. In: Reese, H. (ed.) Advances in Child Development and Behavior, vol. 10. Academic Press, New York (1975)
11. Thorndyke, P.W., Goldin, S.E.: Spatial learning and reasoning skill. In: Pick, H.L., Acredolo, L.P. (eds.) Spatial Orientation: Theory, Research, and Application, pp. 195–217. Plenum Press, New York (1983)
12. Jul, S., Furnas, G.W.: Navigation in electronic worlds: a CHI 97 workshop. SIGCHI Bull. **29** (4), 44–49 (1997)
13. Stevens, A., Coupe, P.: Distortions in judged spatial relations. Cogn. Psychol. **10**, 422–437 (1978)
14. Colle, H.A., Reid, G.B.: The room effect: metric spatial knowledge of local and separated regions. PRESENCE Teleoperators Virtual Environ. **7**(2), 116–128 (1998)
15. Chase, W.G.: Spatial representations of taxi drivers. In: Rogers, D.R., Sloboda, J.A. (eds.) Acuisition of Symbolic Skills. Plenum, New York (1983)
16. Darken, R.P., Peterson, B.: Spatial orientation, wayfinding, and representation. Handb. Virtual Environ. Des. Implementation Appl. 493–518 (2002)
17. Mou, W., Wang, L.: Piloting and path integration within and across boundaries. J. Exp. Psychol. Learn. Mem. Cogn. **41**(1), 220 (2015)
18. Mou, W., Zhou, R.: Defining a boundary in goal localization: infinite number of points or extended surfaces. J. Exp. Psychol. Learn. Mem. Cogn. **39**(4), 1115 (2013)
19. Aoki, H., Oman, C.M., Natapoff, A.: Virtual-reality-based 3D navigation training for emergency egress from spacecraft. Aviat. Space Environ. Med. **78**(8), 774–783 (2007)

Aid for the User-Centered Evaluation of Human Machine Interfaces During Ramp-up of Socio-Cyber-Physical Production Systems

Ina Heine, Patrick Beaujean and Robert Schmitt

Abstract Aim of the present research is the introduction of a self-assessment instrument fostering the user-centered development and evaluation of human machine interfaces during ramp-ups of socio-cyber-physical production systems. This objective is addressed by first outlining the concept of socio-cyber-physical production systems and their specific design restrictions. Then existing user-centered design approaches are analyzed and guiding questions from a user-centered perspective are deduced. The questions are structured under consideration of the agile framework scrum. Applicability of the instrument is tested by conducting a self-assessment with "oculavis", a software environment for smart glasses and other wearable technologies. Results show that the integration of agile and user-centered development remains a challenge in practice and seems to be approached more intuitively than methodical.

Keywords Cyber-physical production systems · Human-systems integration · User-centered design

1 Introduction

In the last few years, there has been an ongoing trend towards collecting and using all types of data in order to improve a variety of outcomes in different areas of our lives. This trend has been enabled by the technical possibilities of inexpensively

I. Heine (✉) · P. Beaujean · R. Schmitt
Chair of Production Metrology and Quality Management,
Laboratory for Machine Tools and Production Engineering,
RWTH Aachen University, Aachen, Germany
e-mail: I.Heine@wzl.rwth-aachen.de

P. Beaujean
e-mail: P.Beaujean@wzl.rwth-aachen.de

R. Schmitt
e-mail: R.Schmitt@wzl.rwth-aachen.de

M. Soares et al. (eds.), *Advances in Ergonomics Modeling, Usability & Special Populations*, Advances in Intelligent Systems and Computing 486,
DOI 10.1007/978-3-319-41685-4_13

storing and accessing huge amounts of data. Individuals start wearing bracelets in order to monitor their daily physical activity and based on these data optimize their lifestyle.

In the manufacturing industry these socio-technological developments have started to become an important asset in dealing with the challenges of rapidly adapting to new requirements or other unforeseeable changes [1]. These trends of big data, the real-time sharing of data within and across organizations, and using data to make (autonomous) decisions as well as the growing collaborative self-conception of organizations are frequently subsumed under the term "*Industry 4.0*" which stands for the fourth industrial revolution, comparable to the ideas behind Advanced Manufacturing Partnership AMP 2.0. In this context it is also frequently referred to cyber-physical production systems (CPPS) which reflect the combination of physical elements like machines with software elements and connecting them through communication networks [2]. Consider cyber-physical systems (CPS) as important enabler for industry 4.0.

The manufacturing industry is traditionally associated with easy repetitive tasks of heavy physical strain which usually could be carried out by low-skilled workers without special pre-existing know-how or problem solving competency. This traditional view of the manufacturing industry is dramatically changing, resulting in various hypothesized future scenarios. The most extreme one might be the scenario of future factories without any people. However more reasonable scenarios are based on the assumptions that the required competencies of the future workforce will change dramatically [3]. Tasks with high physical strain are increasingly taken over by machines and information from analyses of huge amounts of data provide a solid basis for decision making which should be further enriched by human expertise to enhance performance. The phase until newly introduced or (re)configured production systems reach sustainable production is called system ramp-up [4].

In order to actually achieve this superior production system performance, it will become increasingly important to enable employees to interpret the information, create an understanding of the wider system, and increase the acceptance of technology [5]. According to [1] "*One of the keys for practical implementation of the smart factory will be the understanding and consideration of human factors in production systems*" (p. 2). This claim is also in accordance with [6] who state that "*Designs that do not consider the human element will not achieve the maximum level of performance*" (p. 33). The ramp-up of socio-cyber-physical production systems should be therefore strongly determined by human factors methods.

The present paper addresses this issue by providing a design aid, in terms of a logically organized checklist that helps project teams to reflect upon the following overall question: "*Does the human machine interface for this socio-cyber-physical production system meet the standards of human-centered design, so that organizational and individual outcomes are improved?*". The guiding sub-questions are organized according to an iterative development process called "scrum".

The next chapter gives a brief overview of the relevant theoretical background with regard to design restrictions specific to socio-cyber-physical production systems and user-centered design approaches. The third chapter introduces the developed design aid organized around scrum as iterative development framework. Chapter four deals with exemplary applying the design aid to "oculavis", a software environment for smart glasses and other wearable technologies with the objective of shortening information control loops during manual assembly processes by providing information in real-time. Chapter five concludes with a discussion of the results, limitations, and implications.

2 Theoretical Background

2.1 Design Restrictions Specific to Socio-Cyber-Physical Production Systems

As systems and their elements become increasingly technologically advanced, often they are also more difficult to use [7]. It is therefore important to include the user already during the early design stages. Approaches that emphasize human factors during the entire design process are called user- or human-centered and have a long history in safety-critical environments like aviation and nuclear plants.

According to [8] Cyber-physical production systems (CPPS) appear to have specific requirements or restrictions that need to be considered during user-centered design processes. By including humans into these systems, they can be considered socio-cyber-physical production systems or human-machine systems because of the social and technical system elements. Human-machine systems are defined as "*a system in which an interaction occurs between people and other system components, such as hardware, software, tasks, environments, and work structures*" [6, p. 32]. Systems can be distinguished at a very general level like for instance educational systems, production systems, or communication systems and consist of interrelated subsystems and single system elements [6, 9].

Based on this conceptualization, Fig. 1 shows a simplified graphical representation of a socio-cyber-physical production system with an exemplary marked subsystem and system elements. Clearly, the overall system consists of several subsystems and elements.

According to [9], in a complex production system design, it is not sufficient to focus on individual system elements like for instance individual machines. The authors state further that the term human-machine interface covers all subsystems which require functional interactions between humans and a technical system. The interface design appears to be an extremely important issue in the context of Industry 4.0, because its quality is believed to strongly influence perceived system complexity [8]. Since complexity seems to rather increase, due to the huge amount of data and interconnections in future intelligent factories, reducing its perceived complexity is an important step towards increasing overall system performance and acceptance which also allows faster ramp-up.

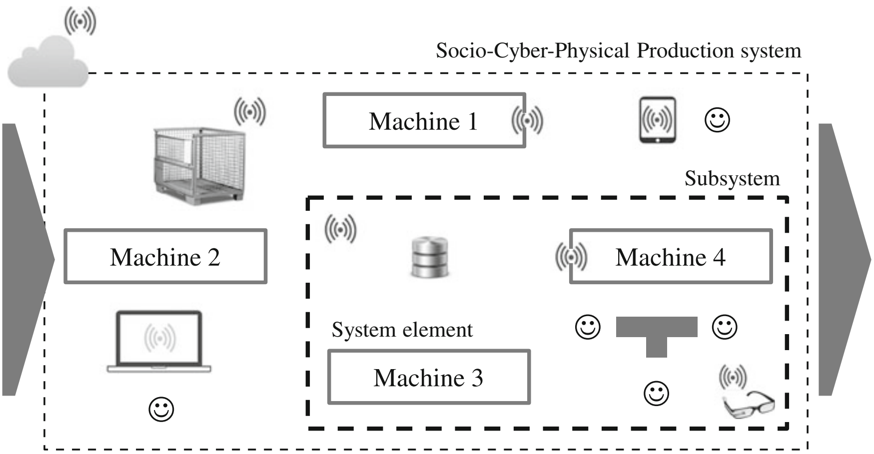


Fig. 1 Simplified graphical representation of a socio-cyber-physical system

Another factor that increases complexity, at least on the short term, is the use of prospective devices which are unfamiliar to workers and therefore might add to the perceived complexity. Devices that are not familiar to the majority of people but receive considerable attention in current research are smart glasses [10]. Also the use of tablets finds wide application in modern factories with the aim to integrate humans in CPPS. However different to other assistive devices like for instance smart glasses, tablets are usually already more familiar to workers as they can be considered as belonging to the technological equipment of an average household.

Other restrictions or peculiarities specific to CPPS identified by [8] include the lack of standardized interaction hardware and toolkits. Appropriate hardware must comply with the demands of industrial environments like for instance robustness and dust protection. Furthermore, there might be design constraints due to existing physical system elements like specific machines that are not easily exchangeable. Because there is still much uncertainty and lack of technological understanding, ramp-ups of CPPS should be based on agile development principles.

Besides these more technical restrictions, shop floor workers are rather low-skilled and it is expected that, due to demographic developments, in the future mostly older employees will perform production tasks [9]. Therefore it is important to understand and address the diversity of users that will have to operate the device before development starts.

Thus overall, there is a need to reduce perceived complexity in socio-cyber-physical systems while considering specific design restrictions. The following chapter provides a brief overview of user-centered design approaches which enable designers to reduce perceived system complexity.

2.2 User-Centered Design Approach

The assumption that the user-centered design of products or systems contributes to improving overall system performance seems to receive general acceptance in research and practice. User-centered design approaches have their origin in the human factors field in which usability is considered critical for performance. As outlined in the previous chapter, the usability of interfaces between humans and machines is an especially important design aspect in the context of socio-cyber-physical production systems.

Usability engineering is a subfield of user-centered design and has been elaborated for the design of software. It involves an early focus on the user, the use of empirical data, and an iterative and participatory design process [7]. The topic of user-centered design has been proven to be so important that a subcommittee of the International Organization for Standardization (ISO TC 159/SC 4) provides standards related to human-system interaction [7]. Differentiates between three categories of guidance for designers: high-level theories and models, basic principles and guidelines, and methods for evaluation and testing. A generally accepted guideline states, for instance, that before first prototypes or design solutions are developed, a front-end analysis should be conducted in order to understand the users and their needs as well as possible demands of the work situation [7]. Possible methods for collecting task analysis data are for instance observation, think-aloud verbal protocols, task performance with questioning, and interviews. After these data have been analyzed and user needs are better understood, designers can start with a description of system specifications and iterative testing.

Brauner and Ziefle [5] categorize methods for developing and evaluating user interfaces according to whether the methods involve the prospective user or not. For instance, methods like paper prototyping and AB-tests involve prospective users in evaluating user performance and capture further aspects like perceived usability and technology acceptance. Methods like heuristic evaluation and cognitive walk-throughs are usually applied without involving prospective users. Instead Subject Matter Experts (SME) evaluate the respective design under consideration of specific performance criteria. Both types of methods have their advantages and disadvantages and should be regarded as complementary. There is, however, wide agreement about the importance of applying human factors methods already during early design phases, because the costs for error correction are assumed to increase exponentially over time [11].

The following chapter provides an overview of approaches to design aids, with the objective of identifying which type might be most useful during the design and development of human machine interfaces in socio-cyber-physical production systems.

2.3 Approaches to Design Aid

In general, design and evaluation aids have the purpose of assisting project teams as decision heuristic. This assisting function can be realized through different means which vary with regard to their rigidity and specificity. For instance, [12] provides a summary of general usability principles that are supposed to account for most usability problems. These guidelines include for instance the need for consistency in terms of color and other design elements providing designers some guidance in taking design decisions. More general aspects regarding the design process like an early focus on users are usually not further considered.

According to [8], iterative processes are seen as "*best practice*" to design user interfaces. Iterative processes allow for more degrees of freedom than strictly sequential processes like traditional product development approaches and are considered state of the art in software development projects. For the development of a design aid in terms of a self-assessment instrument, it seems therefore not useful to provide a detailed procedure in the form of flowcharts with well-specified activities because of their sequential and rigid nature.

Checklists are similar to flowcharts with regard to their sequential appearance in terms of entries usually being read from top to bottom, but not necessarily to their content-related organization, which might be random or logically organized. Checklists find wide application in the context of complex and safety-critical procedures like for instance preparation for landing aircrafts [13]. These checklists are supposed to decrease cognitive load in terms of remembering a sequence of actions in a standard order by heart and thus function as memory aids. Checklists are therefore also often seen as appropriate for operators that have to follow specific and repetitive procedures but not for ergonomists [13].

In order to take into account both process- and content-related guidelines, development teams would have to consult several sources. A more comprehensive set of guidelines could be especially helpful for novices or small companies without direct access to human factors specialists. Therefore, the objective of the present research was the development of a flexible aid that is comprehensive with regard to user-centered design in the context of agile ramp-ups of CPPS. It is thus supposed to support development teams in approaching their projects user-centered which is believed to be positively related to usability.

3 Design Aid for the User-Centered Development and Evaluation of Human Machine Interfaces

The leading question for this aid is "*Does the human machine interface for this socio-cyber physical production system meet the standards of human-centered design, so that organizational and individual outcomes are improved?*" The content of the self-assessment instrument is based on a review of human factors literature and is logically organized according to an iterative and agile development process called “scrum”. This has been identified as promising approach for ramp-ups of CPPS which are very complex and technologically not fully understood yet.

Scrum is an iterative framework for product and software development which consists of incremental steps. It structures development projects in iterative cycles with monthly evaluative meetings. These so called *sprints* have strict deadlines at which working on the respective tasks is stopped—whether the work packages have been really completed or not. For successful sprint performance, precise planning is required. Therefore *sprint planning meetings* are held during which the *product backlog*, which consists of continuously updated features to be focused on in a priority order and determined by the product owner, is divided into individual tasks [14].

This reduced working list is documented in the *sprint backlog*. The prioritized items are intended to be completed by the end of the sprint and meanwhile not changed. In daily meetings, progress is inspected and further steps for completion of the remaining work are identified. At the end, the incremental sprint is reviewed by team members and stakeholders to evaluate the results and to receive feedback that can be implemented in further iterations [14]. However, in order to not only implement and test requirements determined by the product owner, it is absolutely essential to include actual prospective users. The users’ needs and goals should be well understood before or at least parallel to the development process. This seems to be not fully compatible with the objective of agile software development which strive to deliver small packages of software as fast as possible [15, 16].

In order to strengthen a user-centered approach also during agile development projects, the present paper proposes to integrate checklists into the scrum approach providing guiding questions based on user-centered design (cp. Appendix). For instance, in preparing the product backlog, certain key aspects should be focused on before design solutions are generated. The checklist provides guidance in choosing prioritized features for the design and also in filtering these items for the sprint backlog. As product backlogs are understood as “product road map” [14], it includes every feature that should be worked on by the development team in order of priority. The main focus is on the technical system.

For the product backlog, part A of the checklist provides key aspects such as the identification of users, their needs and requirements as well as the description of the system’s requirements and specifications. These items serve as input for the sprint planning meetings. In this phase, further analyses of the product backlog are made in order to select the items which are to be completed in the sprints. For this selection, aspects according to the possibilities of implementation should be considered. The checklist provides questions which take environmental restrictions, hardware standardization and information flows into account. Questions that can be only answered partially should be frequently addressed during regular meetings. Based on the examinations, a detailed task planning and documentation of the sprint backlog is supported. Figure 2 provides a graphical representation of the integrative process described above.

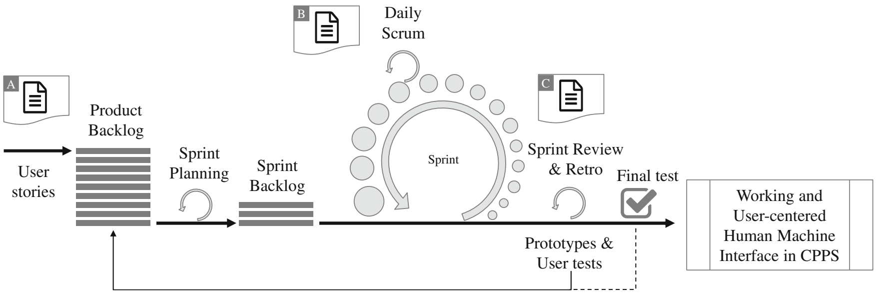


Fig. 2 Graphical representation of integrating checklists into the scrum process

Once the sprint started, the development team engages in the so called *daily scrum*, a short meeting that takes place every workday, to report about the attained progress since the last meeting, objectives for the next meeting and challenges that might prejudice progress [14]. By means of these reports, team members are given assistance in coordinating the design process on an iterative level. Questions that team members should ask themselves include considerations about established interface principles. Related to the daily scrum, the self-managing team should answer further questions when it comes to updating the sprint backlog and the remaining time to complete the current tasks. These questions focus on aspects like the analysis of system functions and goals as well as the consideration of usability metrics.

After this phase, the sprint is reviewed by team members and product owners. Items that are not finished go back to the product backlog and get re-prioritized by the product owner. Based on the review feedback, the team evolves its design process in iterative cycles. For the review procedure, part C of the developed checklist provides questions according to the evaluation of the generated design and includes usability aspects, user focus and the meeting of requirements and standards.

It must be noted that the aid is not meant as strict planning and specification or decision making tool. Instead it serves project teams as self-assessment instrument containing questions that should be reflected upon during the different phases of agile development. Thus it can be considered as internal inspection tool with the aim of emphasizing a user-centered design perspective. Especially for small and medium sized enterprises which usually do not have access to internal human factors specialists might benefit from the presented design aid.

4 Application of the Design Aid

4.1 Method

In order to test whether the developed aid is applicable to real development projects and to receive feedback about its perceived practical utility, a case study was conducted. A case study design is "an in-depth study and detailed description of a single individual (or a very small group)" [17, p. 502].

4.2 Case Description—Oculavis

Oculavis is a software environment for smart glasses and other wearable devices which is based on the operating system Android and the objective of supporting employees doing their daily working tasks. It is developed by a recent spin-off company from Fraunhofer Society and RWTH Aachen University having a strong background in production technology. Currently, this software environment consists of seven modules which aim at different objectives like for instance sharing information and conducting audits from the distant via video telephony. The different modules consist of a set of core functions which can be expanded according to individual requests from customers.

The case study includes applying the self-assessment instrument to the oculavis module named ".share" which enables employees to collaborate without having to be physically near to each other. This reduces for instance the need for employees to travel long distances in order to do supplier audits, thereby saving travel time and costs as well as reducing work stress for the individual employee. It should be noted that the project is already in an advanced state wherefore the self-assessment instrument cannot be applied according to its exact procedure that has been described in the previous chapter.

4.3 Results Case Study

Results of the case study indicate that answering the complete list of approximately 30 questions is rather overwhelming for the test person. However, in a real world scenario, this should be rather exceptional because some of the self-assessment questions should be evaluated positively before different design solutions are developed (cp. Fig. 2).

Furthermore, the test person provided the feedback that answering the questions from top to bottom resulted in a strong perceived sequentiality. This was reinforced by the list-like structure of how the questions were presented. Also the logical organization of questions based on the general process of user-centered design might have contributed to this perception.[1]

Also the suggested methods were considered by the test person as rather hindering because of the required time and effort for applying these methods. It seems that, in practice, the objectives of the different methods like for instance “understanding the user” (method: task analysis; GOMS) are addressed rather intuitive and sometimes implicit. This is a more flexible and less rigid approach, but it also carries the risk of overseeing important aspects which might cause avoidable performance problems with increased costs. This is consistent with the results reported by [16] who found that most studies about integrating agile and user-centered approaches used Little Design Up Front (LDUF) which is based on reduced user-centered work before the project starts. It must be also noted that oculavis is a very recent spin-off which might focus more on advancing technologically than strongly emphasizing user-centered design.

In summary, it can be stated that the integration of agile development and user-centered design is still a challenge in practice. As this integration is believed to be an important factor during ramp-ups of socio-cyber-physical production systems, current approaches require further elaboration. The aid that has been introduced in the present paper appears to be good starting point for subsequent empirical studies.

5 Discussion

Based on a brief review of the specific requirements of CPPS and user-centered design approaches, the present paper provides an aid or self-assessment instrument in terms of a checklist that is logically organized around the scrum framework. In total, the checklist is divided into three parts which are supposed to support project teams during the different iterative development phases. It can be considered as performance support material for the user-centered design of human-machine interfaces in cyber-physical production systems.

In order to test the aid’s practical utility, it was applied to the software module “. share” which belongs to the software environment oculavis. Results of the case study show that the project team addresses many of the issues intuitively by having workshops with the product owner for instance. However, a strong methodological approach was considered rather rigid and too time-consuming.

Limitations of the presented paper include the case choice and example of use. It would have been more useful to accompany a project team with a new project and to use the developed aid during the entire process, like it is intended to be used, instead of retrospectively assessing whether the different user-centered issues have

[1]The questions were presented to the test person without providing a graphical representation that integrates the checklist parts into the scrum process.

been addressed in an ongoing project. Thus the practical utility of the developed aid should be further examined with more cases and empirical studies.

Nevertheless, the integration of agile development and user-centered design remains a challenge and should receive further attention in research. Approaches like sprint 0 (i.e. initial work on user-related issues) or user-centered sprints by design teams parallel to the scrum process require further empirical examination [15]. There is a general need for more rigorously conducted studies in the field of agile user experience research [15, 16]. According to [5] the lack of a shared language and misconceptions about the other methodologies remain a common problem among interdisciplinary teams. It is therefore reasonable to question common team structures which differentiate between design and development teams. This strong functional division might contribute to difficulties in the mutual understanding.

Acknowledgments The support of the German National Science Foundation (Deutsche Forschungsgemeinschaft DFG) through the funding of the research training group "Ramp-Up Management—Development of Decision Models for the Production Ramp-Up" (1491/2) is gratefully acknowledged.

Appendix: Checklist

	Question	Method suggestion	Compliance	Last entry
Product and sprint backlog (checklist part A)	Are the system users identified?	User analysis, personas	◔	02/05/2016
	Are the task and its environment analyzed?	Task and environment analysis		
	Is standardized hardware for the task considered, if available?	Market analysis		
	Are any environmental restrictions regarding hardware considered?	Environment and market analysis		
	Is the information flow within the organization described?	Matrix of information flow		
	Is the information flow across organizations described?	Matrix of information flow		
	Are user needs/goals identified?	GOMS model		
	Are the system specifications/requirements described?	Specifications document		

(continued)

(continued)

	Question	Method suggestion	Compliance	Last entry
Sprint and daily scrum (checklist part B)	Is a function for each need/goal included?	Quality function deployment		
	Are functions without relevant goals excluded?	GOMS model		
	Are the functions allocated (system, person, or combination)?	Functional analysis + cost/benefit analysis		
	Are different design alternatives considered?	Trade study		
	Are signifiers added to the functions?	Heuristic evaluation		
	Are established interface design principles considered?	Human factors guidelines (e.g. Nielsen, 1994; DIN EN ISO 9241-110:2008)		
	Is the usage of signifiers consistent?	Heuristic evaluation		
Sprint review (checklist part C)	Are the signifiers natural to the user?	Use of metaphors		
	Does the user receive timely feedback?	Heuristic evaluation		
	Is support material developed?	Manuals, training programs		
	Are early prototypes developed?	Paper-prototypes, mock-ups		
	Are the usability metrics specified?	General usability principles (Nielson, 1994)		
	Are iterative usability studies conducted?	Heuristic evaluation, usability testing		
	Is the system tolerant to errors?	Heuristic evaluation, usability testing, safety analysis		
	Are all user types included in the study?	User analysis		
	Is the interface customizable?	Quality function deployment		
	Is the interface improved according to the study results?	Prototypes		
	Is the interface in accordance with requirements of ISO-standards?	DIN EN ISO 9241-110:2008		

(continued)

(continued)

	Question	Method suggestion	Compliance	Last entry
	Is a final test (system evaluation) conducted?	Comprehensive human factors test		
	Are social factors like beliefs and attitudes considered?	Cultural audit		
	Is the interface improved according to the study results?	Quality function deployment		

References

1. Brecher, C., Özdemir, D.: Introduction. In: Brecher, C. (ed.) Advances in Production Technology, pp. 1–8. Springer International Publishing, Switzerland (2015)
2. Schuh, G., Reuter, C., Hauptvogel, A., Dölle, C.: Hypotheses for a Theory of production in the context of Industrie 4.0. In: Brecher, C. (ed.) Advances in Production Technology, pp. 11–23. Springer International Publishing, Switzerland (2015)
3. Spath, D. (ed.), Ganschar, O., Gerlach, S., Hämmerle, M., Krause, T., Schlund, S.: Produktionsarbeit der Zukunft-Industrie 4.0. Fraunhofer Verlag Stuttgart (2013)
4. Koren, Y.: Reconfigurable Manufacturing Systems and Transformable Factories. Springer, Berlin Heidelberg (2006)
5. Brauner, P., Ziefle, M.: Human factors in production systems: motives, methods and beyond. In: Brecher, C. (ed.) Advances in Production Technology, pp. 187–199. Springer International Publishing, Switzerland (2015)
6. Czaja, S.J., Nair, S.N.: Human factors engineering and systems design. In: Salvendy, G. (ed.) Handbook of Human Factors and Ergonomics, pp. 32–49. Wiley, New York (2006)
7. Wickens, C.D., Lee, J., Liu, Y., Becker, S.G.: An Introduction to Human Factors Engineering. Pearson, UK (2014)
8. Paelke, K., Röcker, C.: User interfaces for cyber-physical systems: challenges and possible approaches. In: Markus, A. (ed.) Design, User Experience, and Usability: Design Discourse, pp. 75–85. Springer International Publishing, Switzerland (2015)
9. Spath, D., Braun, M., Hagenmeyer, L.: Human factors and ergonomics in manufacturing and process control. In: Salvendy, G. (ed.) Handbook of Human Factors and Ergonomics, pp. 1597–1625. Wiley, New York (2006)
10. Plutz, M., Große Böckmann, M., Siebenkotten, P., Schmitt, R.: Smart Glasses in der Produktion. Studienbericht des Fraunhofer-Instituts für Produktionstechnologie IPT. Studie. Fraunhofer Publica. http://publica.fraunhofer.de/documents/N-389336.html11 (2016)
11. Schmitt, R, Pfeifer, T.: Qualitätsmanagement: Strategien—Methoden—Techniken. Carl Hanser Verlag (2015)
12. Nielsen, J.: Heuristic evaluation. In: Nielsen, J., Mack, R.L. (eds.) Usability Inspection Methods. Wiley, New York (1994)
13. Drury, C.G.: Human factors and ergonomic audits. In: Salvendy, G. (ed.) Handbook of Human Factors and Ergonomics, pp. 1106–1132. Wiley, New York (2006)
14. Sutherland, J., Schwaber, K.: The Scrum Papers: Nuts, Bolts and Origins of An Agile Framework. SCRUM Training Institute (2011)

15. Jurca, G., Hellmann, T.D., Maurer, F.: Integrating Agile and User-Centered Design: A Systematic Mapping and Review of Evaluation and Validation Studies of Agile-UX, pp. 24–32. Agile Conference, IEEE (2014)
16. Silva da Silva, T., Martin, A., Maurer, F., Silveira, M.: User-Centered Design and Agile Methods: A Systematic Review. Agile (2011)
17. Gravetter, F.J., Forzano, L.B.: Research Methods for the Behavioral Sciences. Thomson Wadsworth, Belmont (2006)

Redesign of a Laboratory Website Using User Centered Design Method and WEBUSE

Siti Kurniasih, Andrie Pasca Hendradewa, Amarria Dila Sari and Muhammad Ragil Suryoputro

Abstract Laboratory website is one of the main supporting facility in teaching and learning activities in a university. It contains information about laboratory works and events. Industrial Engineering program of Universitas Islam Indonesia currently have 11 educational websites which are accessed by students in daily routine. Innovation and Organization Development (IOD) is one laboratory that already implemented website technology to support its educational activity. Our preliminary study showed that website from IOD laboratory has the most interface problem compared to the other ones. This study aim to redesign the laboratory website using user centered design method based on three usability aspects that consist of effectivity, efficiency, and personal satisfactory. This study involved 30 participants which are categorized into three different level of experience in using the website, they are expert, intermediate, and beginners. Usability problem was identified using think-aloud evaluation method while those participants worked on representative task. Usability problems found on the website including font size that too small, not included university logo as an identity, not integrated to other laboratory websites, and used unattractive color and background. According to usability problem identification, the average of participant's task completion rate is about 99.4 %, the obstacle was on finding business news and laboratory achievement task. Based on those results, then we redesigned the website using user centered design method that consists of 4 steps including analysis, synthesis using WEBUSE questionnaire, simulation, and evaluation. The results indicated that the usability level identified by WEBUSE questionnaire and usability problem found by interview can be used guideline to redesign website interface when using user-centered design method.

S. Kurniasih · A.P. Hendradewa (✉) · A.D. Sari · M.R. Suryoputro
Industrial Engineering Program, Universitas Islam Indonesia, Jl. Kaliurang Km 14.5, Yogyakarta, Indonesia
e-mail: andriepasca@gmail.com

S. Kurniasih
e-mail: sitikurniasih06@yahoo.com

M. Soares et al. (eds.), *Advances in Ergonomics Modeling, Usability & Special Populations*, Advances in Intelligent Systems and Computing 486,
DOI 10.1007/978-3-319-41685-4_14

Keywords Usability · User-centered design · Webuse · Laboratory website

1 Introduction

Website became a vital part of modern daily life as an information media. Website defined as a group of World Wide Web pages which usually contains hyperlinks to each other and made available online by an individual, company, educational institution, government, or organization [1]. Based on the functionality, website can be utilized as supporting facility in educational activity. By using website technology, academicians will be able to interact with the system from anywhere they want via internet connection.

Usability is a critical aspect to determine the success of an interactive system or product [2]. Usability describes the quality of use while the products or systems are used in a real world [3]. Usability, from the functionality aspect, defined as the ease of use and efficiency when the system or technology used [4]. There are five components that related to usability attribute: learnability, efficiency, memorability, error rate, and satisfactory [5].

Usability of a website represents the quality of a system which describes the interaction between human and technology [6]. Poorly designed and unusable systems will make users find difficult to learn and complicated to operate. These systems are likely to be under used, misused or fall into disuse with frustrated users maintaining their current working methods [2].

Currently, Industrial Engineering program in Universitas Islam Indonesia has 11 educational websites that consist of laboratory, e-learning, e-library, and course management websites which support the academic administration. One implementation of website technology for educational purpose is a laboratory website. Students tend to access the laboratory website to gather information about the courses, news, and events.

We asked for feedback about 11 educational website from 45 students who usually use those website by using the initial questionnaire. Preliminary data showed that Innovation and Organization Development (IOD) laboratory website had the most priority to be improved on its usability aspects among the other educational website. About 33.3 % students clarified that IOD laboratory website needs improvement. IOD is one of our laboratory which already implemented the website technology to support educational activities. Our preliminary study also showed that there are usability problems found on the website, such as: confusing home page, unattractive color and layout, difficult to use, and font size that too small.

In order to create a more usable website, it is important to conduct improvement to an existing website. Usability improvement of a website must go through several usability guidelines to ensure that the purpose of the website can be achieved [2].

Therefore, the improvement of website usability requires a combination of planning to understand the context of system use as a basis to identify and measure system through user testing [7].

WEBUSE known as usability evaluation tool for web-based system in development process that can be used to measure system quality and user satisfactory [8]. By evaluating the interactive system such as website, usability problems in system can be found. Through an improvement or redesign, a more better system and interface can be made. User-centered design (UCD) method is a design process that uses the product as the main focus and aims to obtain the design result which is usable and meets the users needs [9]. The aim of this study is to improve website usability by using user-centered design method based on WEBUSE evaluation.

2 Methodology

There are two main ideas in this study, evaluate the existing website and redesign it to a more usable website. WEBUSE questionnaire was used to evaluate the usability problem in the existing website. According to Chiew and Salim [8], WEBUSE questionnaire contains 4 usability categories as classification of usability evaluation criteria, such as:

1. Content, organisation, and readability: display space, hyperlink description, organisation of information, etc.
2. Navigation and links: information search, link colors, respond according to user expectation, etc.
3. User interface design: follow real world conventions, consistent design, etc.
4. Performance and effectiveness: download time, accessible, back button, etc.

This study use 6 questions for each category. Five options were available for each question. The options and corresponding merits are shown in Table 1.

To determine the usability level, there are five usability points that are shown below (Table 2).

Table 1 Options for WEBUSE questionnaire and corresponding merits

Option	Strongly agree	Agree	Fair	Disagree	Strongly disagree
Merit	1.00	0.75	0.50	0.25	0.00

Table 2 Usability points and corresponding usability levels

Points (x)	$0 \leq x \leq 0.2$	$0.2 \leq x \leq 0.4$	$0.4 \leq x \leq 0.6$	$0.6 \leq x \leq 0.8$	$0.8 \leq x \leq 1.0$
Usability level	Bad	Poor	Moderate	Good	Excellent

Results from WEBUSE questionnaire were used to determine the usability level for each category, user satisfaction, and website usability level.

User-centered design method is a design process that uses the product as the main focus and aims to obtain the design result which is usable and meets the users needs [9]. According to UCD concept by Norman [10], there are four basic suggestions on how a design should be:

1. Make it easy to determine what actions are possible at any moment
2. Make things visible, including the conceptual model of the system, the alternative actions, and the results of actions
3. Make it easy to evaluate the current state of the system
4. Follow natural mappings between intentions and the required actions, between actions and the resulting effect, and between the information that is visible and the interpretation of the system state.

By following those suggestions, it means the redesign process place the user at the center of the design.

Participants. The preliminary study involved 45 students of industrial engineering program in Universitas Islam Indonesia with age 18–21 years old to give feedback about the educational websites. Then, from those students, 30 people were chosen as participants based on the intensity of accessing website (more than 4 times in a week). They were divided into three groups based on different experience level: beginner (use IOD laboratory website only for looking the basic information they need), intermediate (use IOD laboratory website to understand the basic concept), and expert (use IOD laboratory website for having good understanding to the whole concept). Each group consists of 10 participants.

Procedure. The existing system (IOD laboratory website) was evaluated by 30 participants using WEBUSE questionnaire. Then, 5 participants from expert group were involved in experiment and interviewed about the usability problem experiences. Experiment took about 30 min to complete for each participant. Participants were given tasks or scenarios to complete in the experiment, while participants success rate and completion time per task were measured. Then system interface was redesigned based on the evaluation result from WEBUSE questionnaire and interview.

Tasks. Participants was given several tasks to complete, then the completion time and success rate can be measured. Tasks that given to participants consists of:

- Download the laboratory course material (Task 1)
- Find laboratory news and announcement (Task 2)
- Find laboratory and assistant profile (Task 3)
- Find laboratory achievement (Task 4)
- Find business news in laboratory website (Task 5)

3 Findings and Results

Usability level. Evaluation results from WEBUSE questionnaire are shown below:
Content, organisation, and readability:

$$x = \frac{[\sum(merit\,for\,each\,question\,per\,category)]}{[number\,of\,question]} = \frac{3.5}{6} = 0.58$$

Navigation and links:

$$x = \frac{[\sum(merit\,for\,each\,question\,per\,category)]}{[number\,of\,question]} = \frac{3.33}{6} = 0.555$$

User interface design:

$$x = \frac{[\sum(merit\,for\,each\,question\,per\,category)]}{[number\,of\,question]} = \frac{3.5}{6} = 0.59$$

Performance and effectiveness:

$$x = \frac{[\sum(merit\,for\,each\,question\,per\,category)]}{[number\,of\,question]} = \frac{3.3}{6} = 0.55$$

Those results indicated that the usability level of IOD laboratory website, based on WEBUSE category, all values are in between 0.4 and 0.6 (moderate level).

User satisfaction. Evaluation results from WEBUSE questionnaire are shown below:Content, organisation, and readability:

$$x = \frac{\sum usability\,level}{\sum participant\,x \sum question} \times 100\,\% = \frac{0.58}{30\,x\,6} \times 100\,\% = 11.6\,\%$$

Navigation and links:

$$x = \frac{\sum usability\,level}{\sum participant\,x \sum question} \times 100\,\% = \frac{0.55}{30\,x\,6} \times 100\,\% = 11.11\,\%$$

User interface design:

$$x = \frac{\sum usability\,level}{\sum participant\,x \sum question} \times 100\,\% = \frac{0.59}{30\,x\,6} \times 100\,\% = 11.97\,\%$$

Table 3 Success rate of task completion

Participants	Success percentage (%)					Average of success rate per participants (%)
	Task 1 (%)	Task 2 (%)	Task 3 (%)	Task 4 (%)	Task 5 (%)	
P 1	100	100	100	95	100	99
P 2	100	100	100	100	100	100
P 3	100	100	100	100	100	100
P 4	100	100	100	95	95	98
P 5	100	100	100	100	100	100
Average of success rate per task	100	100	100	98	99	

Performance and effectiveness:

$$x = \frac{\sum usability\,level}{\sum participant\,x \sum question} \times 100\,\% = \frac{0.55}{30\,x\,6} \times 100\,\% = 11.19\,\%$$

Those results indicated that the user satisfaction to the whole IOD laboratory website is about 11.6 % + 11.11 % + 11.97 % + 11.19 % = 45.87 %

Website usability level. Evaluation results from WEBUSE questionnaire are shown below:

$$x = \frac{\sum usability\,level}{total\,categories} = \frac{0.58 + 0.55 + 0.59 + 0.55}{4} = \frac{2.27}{4} = 0.56$$

The result indicated that usability level of the whole IOD laboratory website, based on the WEBUSE usability point, the value is on the moderate level

Success rate of existing website. Tasks completion in experiment are shown below (Table 3):

Those results indicated that task 4 and 5 have success rate 98 and 95 %. That means, those task have usability problem, so it cannot be completed by participants.

Efficiency of existing website. Completion time from experiment are shown below (Table 4):

The results indicated that task 1 has the quickest completion time, on the other hand task 5 needs the most of time to be done. The quicker a task can be completed, the more efficient participants did the task.

Usability problem of existing website. Usability problem was identified through interview to 5 participants from the expert group. All usability problem found listed on the table below (Table 5):

Table 4 Efficiency of task completion

Participants	Completion time (s)					Average of completion time per participants (s)
	Task 1	Task 2	Task 3	Task 4	Task 5	
P 1	10	35	50	61	77	46.6
P 2	12	30	55	61	75	46.6
P 3	17	45	45	40	53	40
P 4	30	37	60	54	79	52
P 5	32	31	54	49	70	47.2
Average of completion time per task (s)	20.2	35.5	52.8	53	70.8	

Table 5 Usability problem found

Number	Usability problem
1	Website menu does not organized
2	Download menu does not contain clear information
3	Unattractive web layout
4	Search icon does not quite visible, too small
5	Font size too small
6	IOD laboratory website does not integrated to another one
7	IOD laboratory website does not integrated to social media account
8	Aspiration and suggestion box does not available
9	IOD laboratory website does not allow file sharing from lecturer
10	University logo does not available
11	Information about IOD laboratory research does not available
12	IOD laboratory research group or community does not available
13	Difficult to find an information about the lab work
14	IOD laboratory event menu does not available

The results showed that the existing IOD laboratory website contains 14 usability problems that need to be fixed in the redesign process.

Results of redesign process. An improvement has been made based on usability problems found before. The comparison of the existing and the new IOD laboratory website layout are shown below (Figs. 1):

The new interface of IOD laboratory website was redesigned by considering the usability problems found before. Then, all 14 usability problems were not found on the new website interface.

Fig. 1 Interface layout of existing website

4 Conclusion and Recommendation

The objective of the present study is to make an improvement to an existing laboratory website interface using user-centered design method based on webuse evaluation. Our prelimnary study, indicated that 33.3 % students report that the IOD laboratory website need improvement. By conducting interview, all 14 usability problems found by students in expert group. Further research will be expected to evaluate the redesigned website interface by considering usability expert assessment. So, the more complete usability problem can be founds.

References

1. Merriam-Webster Dictionary. http://www.merriam-webster.com/dictionary/Web%20site (2015)
2. Maguire, M.: Method to support human-centered design. Int. J. Hum Comput. Stud. **55**(4), 587–634 (2001)
3. Bevan, N.: Measuring usability as quality of use. Softw. Qual. J. **4**(2), 115–130 (1995)
4. Shackel, B., Richardson, S.J.: Human Factors for Informatics Usability. University Press, Cambridge (1991)
5. Nielsen, J., Mack, R.: Usability Inspection Methods. Wiley, New York (1993)

6. Matera, M., Rizzo, F., Carughi, T.G.: Web usability: principle and evaluation methods. Web Eng. 143–18 (2006)
7. Bevan, N.: International standards for HCI and usability. Int. J. Hum. Comput. Stud. **55**, 533–552 (2001)
8. Chiew, K.T., Salim, S.S.: WEBUSE: website usability evaluation tool. Malays. J. Comput. Sci. **16**(1), 47–57 (2003)
9. Smith, C., Thorp, J.: In: Notes on User Centered Design Process (2004)
10. Norman, D.: The Design of Everyday Things. Doubleday, New York (1988)

Guidelines and Best Practices for Open Source Transit Trip Planning Interfaces

Lisa Jo Elliott, Marvin Valarezo, Cody Freeman, Matthew Scott and Michael Moore

Abstract Open source mass transit trip planning applications provide real-time transit information for a local community. The application provides local users with an inexpensive and accurate way to predict when their bus will arrive at the bus stop. Researchers and instructors have used the One Bus Away application as an opportunity to form cross-disciplinary development teams similar to the ones that students will experience in professional development environments. The study shares the lessons learned, the guidelines developed, and the best practices for designing transit trip planning interfaces during two implementations. User testing revealed that online mapping applications must support both riders who are familiar with the city (i.e., resident riders), as well as riders who are only visiting (i.e., visiting riders). In both cases, riders must rapidly understand the interface icons and metaphors during significant cognitive stress, environmental stress, and anxiety about missing their bus.

Keywords Transit · Mapping · Google maps · One bus away · Mass transit · Human-systems integration · Systems engineering

L.J. Elliott (✉) · C. Freeman · M. Scott · M. Moore
Missouri Western State University, St. Joseph, MO, USA
e-mail: lelliott3@missouriwestern.edu

C. Freeman
e-mail: cody.ux@gmail.com

M. Scott
e-mail: mscott21@missouriwestern.edu

M. Moore
e-mail: mmoore32@missouriwestern.edu

M. Valarezo
University of South Florida, Tampa, FL, USA
e-mail: marvinvalarezo@gmail.com

M. Soares et al. (eds.), *Advances in Ergonomics Modeling, Usability & Special Populations*, Advances in Intelligent Systems and Computing 486,
DOI 10.1007/978-3-319-41685-4_15

1 Introduction

Online mapping applications such as One Bus Away [1] provide directions and information about public transit for a specific locale. People like the real time bus departure and arrival times provided by these and similar applications because it allows them to plan a trip in advance. The rider also knows when the next bus will arrive as they wait at the bus stop. In addition the transit authority receives better data on who uses the public transit system, what routes are the most popular, and when riders access the system most [2].

When Ferris and Watkins began the One Bus Away project in 2008 [3], their goal was to increase the usability and use of the Puget Sound public transit system. Since this initial implementation, they have posted the project to GitHub. Nine cities have successfully implemented the One Bus Away application in their transit system [4]. Moreover, Tang and Thakuriah found that the One Bus Away application helped to improve ridership in the city of Chicago [5].

This study extends One Bus Away to two cities: Tampa, Florida and St. Joseph, Missouri over a three-year period. In this study, we focus on the best practices and lessons learned in User Interaction Design over both implementations. This work summarizes what we found in terms of the logical fidelity for the implementation of future One Bus Away projects.

Logical fidelity is arguably the most important part of the application planning process. If the application does not act as the user expects, or the user has trouble interacting with the application, the application is not used. Simply put, if it is difficult to use, then it does not exist.

We conducted ethnographies, heuristic evaluations, and user testing. The recommendations and best practices listed are agnostic to any trip mapping application.

2 Ethnography

2.1 Types of Riders

In our initial ethnographic work, we identified two types of riders: residents who were familiar with the city and visitors who were not familiar with the city. Within these two types, there were two dispositions: riders who viewed public transit as inconvenient and difficult, and riders who viewed public transit as convenient but were unfamiliar with the local system. Riders who viewed public transit as convenient were likely to use any application that may help them understand the local public transit system or allowed them to use it efficiently. Riders who viewed public transit as inconvenient could be persuaded to use the application if its usefulness overcame the inconvenience of public transit. We focused on the group of riders who already use public transit.

We found that people thought of traveling by bus differently than they thought of traveling by car. When traveling by bus, they felt that they must carefully plan the trip prior to taking it. When travelling by car, they did not feel like they had to plan the trip first. We hoped that the application would change this preconception and inspire people to explore the bus system as they would explore roads in a car.

We also found that people use public transit applications for several reasons. They want to minimize the time that they wait at a bus stop. They want to take the correct bus and know that it will go to their destination. They also want to relieve anxiety about the whole process. If the person is a new bus rider or visiting, the anxiety is especially pronounced. These visiting riders have many questions that current applications do not address. After this initial information, we decided that there were two groups of riders: Resident riders who were familiar with the city and the transit system, and visiting riders who may not be familiar with either the city or the transit system.

2.2 Resident Riders

Tampa, Florida, is a medium sized city with substantial tourism. We estimated that 70 % of the population had ridden public transit at some point. This estimate came from a random sample of the riders that we tested and observed. Most of them were familiar with a similar public transit application. They compared the One Bus Away app (OBA) to Google Maps with a transit function.

The stakeholders in Tampa felt that the system needed more buses and that the buses needed to come more often. We found that there was an hour wait for a bus at a bus stop in Tampa. Tampa stakeholders stated that without ridership increases, the transit system was unable to justify an increase in routes or frequency. They hoped that the application would increase ridership particularly among tourists in Tampa.

The Tampa implementation of OBA was tested on riders who lived in Tampa. These results comprised our resident riders' recommendations.

2.3 Visiting Riders

St. Joseph, Missouri, is a small city without substantial tourism. We estimated that less than 1 % of the population ride the city public transit at some point. None of the users tested were familiar with either the transit system or a transit application. In this city, mass transit was considered a "back-up" in case a person's car broke down or the roads were too treacherous to drive on. The bus system in St. Joseph is unique in that they have a team of dispatchers who monitor a call center. Riders can call and find out where the bus is currently located, they can request that the bus pick them up at a non-bus stop location (e.g., a deviation) or they can request other information. This has been a stalwart tradition that the transit manager did not wish to disband in favor of the mobile application.

The St. Joseph stakeholders also felt that the system needed more buses. The stakeholders wanted to help their current riders and hoped to gain additional riders with the application. The stakeholders stated that, "Until you have used the local transit system, it is impossible to understand." They felt that their system was intimidating and an application would help it seem more accessible. They looked forward to gathering data that would help justify increased routes and bus frequency.

This transit system was in the Northwest Corner of Missouri near the Iowa/Nebraska border. The city can receive over ten inches of snow, which makes many side streets impassable to cars. In the summer, many city roads undergo road construction and close, detouring the traffic; both issues will close or reroute busses. The application needed a way to tell riders about a route change due to snow or road construction.

In the St. Joseph system, the ethnographers discovered that very few riders used mobile devices on the bus, but that most riders had a smart phone. Riders called dispatch to check on the status of their bus. We were unable to determine if they would use a mobile application for the same purpose. Some riders stated that they would still prefer to call dispatch and talk with a human.

The Tampa and the St. Joseph implementations of OBA were tested on St. Joseph residents. Because of the infrequency of bus use, they were considered visiting riders.

3 Methods

3.1 Heuristic Analysis

For the heuristic analysis, eight visiting riders and eleven resident riders used the criteria in Nielsen [6] and in Budd [7] to evaluate both the desktop and the mobile version of the Puget Sound version of OBA. Their evaluation task was to find the next bus arriving at a certain cross street and take the bus to a specific address. They took two passes through the application, then they discussed their findings with each other, and reported their findings in writing. Next, the same groups used the Tampa version of OBA to plan travel to the restaurant near the university at noon. They took two passes through the application, discussed their findings and reported their findings in writing.

3.2 User Testing

We did user testing with two groups of users: resident riders and visiting riders. In both, we asked the participants to do five tasks using the Tampa OBA:

1. Find the app
2. Locate the CAMLS building
3. Identify Route #30
4. Identify when the next bus would arrive
5. Determine where was the bus currently

4 Results

4.1 Searching for an Address

Riders expected the application to auto search when they entered an address. Riders also expected that it should have a "Did you mean…" pop-up box when an address was entered incorrectly. This was the top comment and the most frequent error in both groups. Sometimes the error will be invisible to the rider as he types in street for blvd or road. The riders wanted the system to ask the user to choose from a small set of options when an inconsistency was detected.

For riders who do not know the area, they will not know common street names and addresses. Popular tourist destinations should be coded by frequent search terms. Riders mentioned that they would want a search function, if possible, to find local museums, restaurants nearby, hotels and other venues.

4.2 Rider Help and Errors

During the heuristic analysis, analysts notice the lack of a help function and when one was present, it was not helpful. The help function should tell riders the following items: what went wrong, how it went wrong, and how to fix it. Riders made the following suggestion of ways that they would want to learn more about the errors they made with the application:

– Warning boxes when there are system problems or bus problems
– Warn the riders if the route has no transfers
– Tutorials on YouTube
– A help function as a side bar that could be hidden for expert riders
– Mouse-overs to explain the icons

4.3 Address Errors

One of the most frequent errors that all riders encountered was that no one knew the physical street address of the restaurant near campus. This happened during the heuristic evaluation. Riders knew how to drive to the restaurant but could not find the street address because it was in a shopping mall. In this case, an error box should appear with suggestions (i.e., did you mean?) and be informative as to the error.

For the visiting riders, they stated that they wanted to talk to a human when the system made an error. This might work with small transit systems, but with large transit systems, it may not. Incorporating voice response may be a comfortable alternative.

4.4 GPS Error

If the global positioning system (GPS) is not active on a phone or other device, the locating service does not work. There should be an alert box telling the user how to turn on the GPS on her or his device.

4.5 Search Errors

Riders commented that searches do not take you to the most logical choice. One rider said, "I saw the other choices on the side bar after I got frustrated with the first search result." The visiting riders did not want to see only the "best itinerary," they wanted options to select other routes. One visiting rider stated, "What if I want to see more of the city?"

4.6 New User Errors

The system should ask the rider if they have ever used this transit system before. If the rider selects NO—the system should present onboarding screens. If the rider selects YES—they should have the option to access the onboarding screens.

The visiting riders said that the icons were difficult to understand. It would be helpful to have a legend or some way to drill down to discover what different icons meant. Riders liked the start and end flags and how they could move them around on the map.

4.7 Bus, Route, Stop Errors

When we tested visiting riders, they entered the address and then selected the enter button. We changed the wording on the button to “find my bus” and they liked it. These words communicated better than standard words such as “submit” or “enter.” Visiting riders said that they preferred the application to be based on visual/spatial maps rather than on a list of routes. People can figure out where they are on a map but have difficulty understanding a list of the routes and bus numbers.

One visiting rider stated, “Why do we have to have a route number and a stop number, it’s confusing to have so many numbers to remember.” Visiting riders had trouble keeping the bus information distinct from the route numbering and from the stop numbering. In general, we know that users cannot remember numbers well unless they are less than three characters long. One user said, “It was like remembering the latitude and longitude coordinates—I have no idea what the numbers mean, having to remember the bus number, the route number, and the stop number is impossible.”

One possible solution may be to use letters and colors rather than numbers or in addition to numbers. People can remember a three-letter combination better than they remember a three number combination. If the letters were arranged in a meaningful way such as a consonant vowel consonant pattern—it will help with the memorability. The IBG bus becomes the BIG bus. Overall, increasing the distinctiveness between bus identification, route identification, and stop identification can help prevent rider error and help to improve tracking from route location, bus location, and bus stop listing.

4.8 Other Transportation Options and Missed Bus

Riders reported that sometimes the bus does not go where the rider needs to go or sometimes the bus is the slowest option. Several visiting riders asked for links to rental bikes, rental cars, cabs, rideshares, and a link to Google Maps.

The riders stated that the view of the transit map should scale so that the rider can see nearby stops. The rider should be able to see a street view of the bus stop, “so that you know what it looks like when you are nearby.” When the rider relies on addresses on buildings to find the stop, sometimes the addresses are missing or do not exist.

Several riders stated that it was nice to be able to click on each stop and see the bus arrival and departure times. This helped them know which stop was theirs. They also said that it helped them to understand the route better.

One rider mentioned that there should be a timer or clock that counts down until the bus arrives. He mentioned that this would help him understand how much time he had left until the bus arrived. The stakeholder for the St. Joseph system mentioned that they serve the cognitively and developmentally impaired. The St. Joseph

Transit stakeholder was interested in tools that would help riders understand how much time was left until the bus arrives for this special population of riders.

4.9 Time or Distance

During development, several questions arose about all transit applications. One of those questions concerned how to describe when the bus would arrive at the stop. Some on the development team felt that the "time until the bus arrives" would be the best option. Others on the development team felt that the "distance that the bus is from the stop" would be the best option. To test this choice, we conducted A/B testing with an identical interface. One interface used the time metaphor while the other interface used the distance metaphor.

For visiting riders, who were not accustomed to riding a bus, 90 % of them preferred to view the time until the bus would arrive at the stop. They found the time to be more intuitive and they had a better understanding of the time interface. On a seven point scale with 1 = very good, 7 = very poor, visiting riders rated the "time" interface as 1.33 (very good) for intuitiveness and 1.3 (very good) for interpretation. When the same interface displayed "next bus information" in units of distance instead of time, the ratings were less satisfactory. Visiting riders rated the distance interface as 5.33 (poor) for intuitiveness and 4 (neutral) for interpretation.

Anecdotally, we found that riders who are familiar with traffic and the rhythm of the transit system prefer distance. New or visiting riders prefer time. Thus, we recommend that if it is possible for the development team to allow riders to choose which way they would prefer to view the information, this would be ideal solution. If the development team must choose between time and distance, time should be the default.

4.10 Memory

Many of the transit applications that we reviewed offered the option of sharing on social media. Most riders stated that they would never use this function because of privacy concerns. They would rather have bookmarks or a memory that they can set and erase. They wanted the memory to include their favorite routes and stops in comparison to a GPS in the car. One rider stated that he wanted a "home button", so that he could just press "home" like on his GPS and it would take him there.

Riders also wanted breadcrumbs, as in dots that would allow them to track back to the places that they had been before as they used the application. This was in addition to bookmarks, which helped them recall prior trips.

Several riders stated that there is no way to plan a trip in the future and save it. One rider said, "what if I am traveling and want to know how to get from the subway to the hotel and save it for when I go on vacation and am actually there?"

Over all of the riders tested, everyone supported the idea of bookmarks, trip saving, and breadcrumbs.

4.11 Refresh Rate and Trusting the System

Several visiting riders felt that the application lagged. This could have been because of work that was being completed at the time of testing or something else. The visiting riders said that the app needs a loading screen or circle to appear when the app is working. The user should know that it is doing something. When it cannot display the answer after pressing the button "find my bus" a rotating circle or a rotating hourglass would help them to know that they should wait before trying another command.

Visiting riders noted that the application will show arrival times that are not accurate. This leads to a very unreliable schedule if the rider needs to use another bus. One rider said, "Unless I knew that this was accurate always, and the buses were infrequent at my stop, I would never use it." The visiting riders commented that it was unclear if the times were a live feed or standard route times. The resident riders assumed that the times were a live feed. Developers should share that information with mouse-overs.

4.12 Helping the Transit Authority

In addition to gathering a rider's data on the frequency of different routes, stakeholders wanted additional information about the quality of the bus rides. The stakeholders in St. Joseph wanted a section of the interface devoted to quality improvement. They wanted to know several items such as, was the bus on time, what was the quality of the ride, what was the quality of the bus, and how was the riding environment meeting the riders' expectations? This was beyond the scope of the current development. Future developers may wish to include it.

Acknowledgments We want to acknowledge the two development teams: the Center for Urban Transportation Research at the University of South Florida—Dr. Sean Barbeau, Tracy Wolf, and Mona Fathollahi, and the development team at Missouri Western State University—Deborah Becker, Anna Lathrum, Aaron Munsell, Ali Al Musafir and Ashley Huffman. We also acknowledge the other researchers and the designer that helped on this project, James Foster (Graphic Designer, USF St. Petersburg), Yusnavy Gonzalez (HCI), Chris Gleason (HCI), Kim Johnson (HCI), Steve Bravo-Brown (HCI), Anthony Bellucia (HCI), Yesenia Costa (HCI), Ralph Mahoney (HCI), Safiyyah Sorathia (HCI).

References

1. Budd, A.: Web heuristics. Retrieved from www.andybudd.com/archives/2007/01/heuristics_for_modern_web_application_development/ (2007)
2. GitHub: OneBusAway. Retrieved from GitHub https://github.com/OneBusAway/onebusaway/wiki (30 Mar 2015)
3. Gooze, A., Watkins, K., Borning, A.: Benefits of real time information and the impacts of data accuracy on the rider experience. In: Proceedings of the Transportation Research Board 92nd Annual Meeting. Transportation Research Board, Washington, DC (2013)
4. Nielsen, J., Molich, R.: Heuristic evaluation of user interfaces. In: Proceedings of CHI '90. ACM, NY (1990)
5. OneBusAway: OneBusAway research. Retrieved from http://research.onebusaway.org/ (30 Mar 2015)
6. OneBusAway Research: History. Retrieved from OneBusAway Research http://research.onebusaway.org/history/ (30 Mar 2015)
7. Tang, L., Thakuriah, P.V.: Will psychological effects of real time transit information systems lead to ridership gain? Transp. Res. Rec. **2216**, 67–74 (2012)

Quantifying Visual Attention—Modeling Effects of Object Size

Haruka Yoshida, Azusa Furukawa, Teruya Ikegami, Shin'ichi Fukuzumi and Kazuo Furuta

Abstract In order to develop a visual attention model for quantifying effects of object size, we made a hypothesis that the visual attention by object size of rectangle can be quantified by the width and height of object. To verify the hypothesis, we carried out an experiment with 18 participants. As a result of the experiment, we found that width, height, and interaction between them are effective factors for quantifying the visual attention by object size. From the comparison of estimation accuracy with the existing model based on pixel level position, we found that the proposed model based on the width and height of object has an equivalent estimation accuracy to the existing model. We concluded therefore that the visual attention by object size of a rectangle can be quantified by the width and height of object.

Keywords Visual attention · Size of rectangle object · Human error · Perception · Psychological experiment

---

H. Yoshida (✉) · A. Furukawa · T. Ikegami · S. Fukuzumi
NEC Corporation, 5-7-1, Shiba, Minato-ku, Tokyo, Japan
e-mail: h-yoshida@hg.jp.nec.com; h-yoshida@cse.t.u-tokyo.ac.jp

A. Furukawa
e-mail: a-furukawa@bc.jp.nec.com

T. Ikegami
e-mail: t-ikegami@ct.jp.nec.com

S. Fukuzumi
e-mail: s-fukuzumi@aj.jp.nec.com

H. Yoshida · K. Furuta
The University of Tokyo, 7-3-1, Hongo, Bunkyo-ku, Tokyo, Japan
e-mail: furuta@rerc.t.u-tokyo.ac.jp

M. Soares et al. (eds.), *Advances in Ergonomics Modeling, Usability & Special Populations*, Advances in Intelligent Systems and Computing 486,
DOI 10.1007/978-3-319-41685-4_16

1 Introduction

In business systems, reducing human errors has become an important issue, because system failures and fatal accidents due to human errors are increasing recently [1]. Reason [2] defined human error as “a planned sequence of mental or physical activities fails to achieve its intended outcome.” There are many existing researches about category of human errors and Norman [3] categorized human errors from a viewpoint of human information processing. The human information processing and the process of behavior consist of phases of perception, cognition, comprehension, planning, and action, and he mentioned that a human error is possible to occur in any phase. Norman categorized a human error by the phase where it occurred.

In these types of errors, we focus here on errors in the perception phase, because if an error in the perception phase occurs, it finally causes manifestation of erroneous human behavior with a high possibility even if there are no errors in the other phases. Norman defined a human error in the perception phase as mistake. From a viewpoint of screen design, if the users can accurately perceive information from the screen just as the developers intended, they can understand situations accurately and efficiently, because they can easily attend to important information. On the contrary, if the users perceive information in a manner different from what the developers intended, they possibly make errors such as action omissions and mistakes of judgement, because they are likely to miss important information. The developers, therefore, need optimally design the salience of each information presentation with appropriate color and size on screens.

In business systems such as air traffic control and monitoring management systems where reducing errors is especially important, many kinds of information are usually displayed in one screen, because the users have to understand many kinds of information in parallel. On such a screen, the developers have to design the salience of each information optimally by satisfying many usability requirements such as sufficient contrast against the background and color harmony. Designing the screens that display many kinds of information at once is difficult even for expert designers. Here, if visual attention to information presentation is quantified, the developers can objectively evaluate the visual attention considering the importance of the information and can easily make improvement plans. Namely, the developers can specify problems in designing screen displays where the order of visual attention measure does not match that of the importance of information by simple comparison. As for improvement plans, the developers can adjust object color and size by referring to the visual attention measure.

In this study, we aim to develop a visual attention model (evaluation function) which enables quantifying the effects of geometrical features of objects on a screen to visual attention. Here, we define the visual attention measure as a metric of attention to an object in visual perception level caused by its salience. We have focused on color [4], size, and relative position (distance from the point-of-regard) [5] as the essential elements of visual attention model for screen design and have proposed models in terms of these features. We selected these elements from a viewpoint of the effects to visual attention [6], difficulties in subjective adjustment, possible use not for emphasizing purposes, and frequency of use on display screens. To develop models for screen design application, both formulating the effects of each element to visual attention and verifying the accuracy on the real screens are necessary. As the first step, we focus here on visual attention by object size and we quantify and formulate human sensory perception for visual attention. If applying the model to the screen design evaluations, pixel unit is too microscopic for the developers to adjust geometrical features of object for appropriate visual attention. We therefore aim to quantify and formulate visual attention to object size by simpler parameters than pixel.

2 Existing Model and Requirements for Screen Design Application

Visual attention models were studied in the research area of image processing where the targets are pictures and advertisements [6–8]. Considering application of the models to the screen design evaluation, we expected Tanaka's model [6] was appropriate, because the most screens have objects such as icons and operational buttons, and his model targets at calculating visual attention by object size. In this section, we describe the model as an existing visual attention model by object size and discuss the requirements for applying it to screen design evaluation of business systems.

2.1 Existing Visual Attention Model by Object Size

In the existing model, visual attention is defined by absolute attention to an object (feature visual attention) and relative attention to objects (heterogeneous visual attention) [6]. We focus here on the feature visual attention by object size. The existing feature visual attention by object size is defined by the following Formula.

$$Feature\ visual\ attention(PS_i) = \sum_{x \in RX_i, y \in RY_i} \frac{1}{2\pi\sigma^2} \exp\left(-\frac{(x-cx)^2 + (y-cy)^2}{2\sigma^2}\right)$$
$$where, \quad \sigma = 2Pix \times d \times \tan\frac{\theta}{2} \tag{1}$$

x	x-coordinate of a pixel
y	y-coordinate of a pixel
cx	x-coordinate of point of regard

cy y-coordinate of point of regard
RXi, *RYi* Set of pixels of the object (*i*)
d Proportion of screen's height to visual distance
Pix Pixels of screen's height
θ vertical view angle (20°–30° in usual)

In the above Formula, the feature visual attention by object size is defined with the coordinates of the point-of-regard and pixels of the object. Namely, the model expresses that the lower the visual attention becomes following a Gaussian function the farther pixel departs from the point-of- regard. The feature visual attention by object size is determined as the total sum of visual attention to all pixels of the object. This means quantifying the visual attention by object size and shape at the same time.

2.2 Adjustment of Existing Model Considering Application to Screen Design Evaluation

In this study, we suppose a use case of visual attention where the developers can objectively judge if important information stands out by applying the visual attention model and if there are some problems, and where they can easily make improvement plans using the model. Figure 1 shows the use case of the visual attention model.

We here regard the components of screen displays for business systems such as icons, operation buttons, and tabs as objects. The importance of each object is usually associated with the business requirements. In specifying problems in screen design, the developers check the visual attention measure of each object, which is evaluated using the model, and specify the parts where the order of visual attention

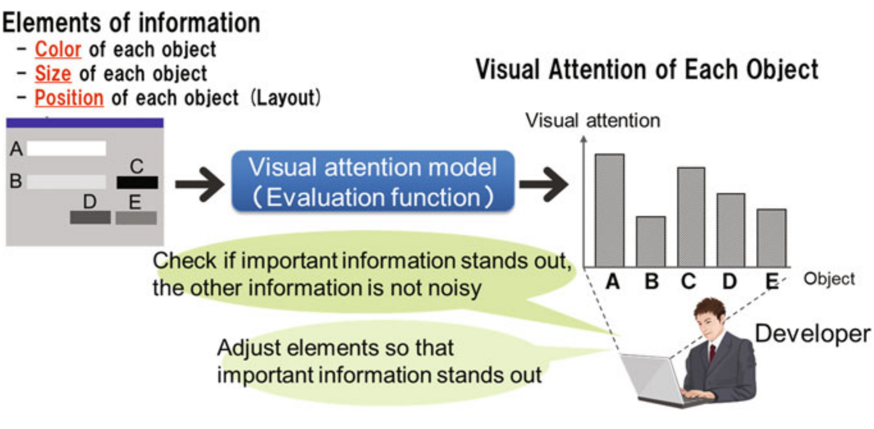


Fig. 1 Use case of visual attention model

does not match that of the importance as problems. In the case of Fig. 1, while the order of object importance is A > B > C > D > E, the visual attention to object B is lower than the other objects. The developer can find this problem, and then adjust color and size of object B so that visual attention measure becomes appropriate in correspondence with the object importance. He or she can also check with the numerical values of visual attention measure if the value for the less important objects such as object D and E are small enough in comparison with object A.

The existing visual attention model by object size calculates the salience value from the object position at a pixel level and formulates implicitly the effects of visual attention by size and shape. If applying Formula (1) to screen design evaluation, the model can calculate visual attention reflecting difference of size and shape of icon, symbol, and letter. It is however difficult for the developer to adjust object shape by a pixel level toward appropriate visual attention. If the modeling parameters are more aggregative than a pixel level, the developer can easily utilize the model for screen design evaluation, because they can adjust geometric feature of objects such as size and shape for better visual attention.

3 Hypothesis of Feature Visual Attention by Object Size

To solve the problem of the above section, we tried to formulate the effects of object size on feature visual attention by simpler parameters than pixel positions. On screens of business systems, rectangular objects are often used. If the object shape is simple as rectangles, we may be able to formulate the feature visual attention by size and shape with more aggregative parameters than pixel positions. To make sure of this assumption, we tried to quantify only the effects of object size on the visual attention without considering the effects of object position. From this point forward, we call the function for quantifying the effects of visual attention by object size the feature visual attention model of size.

As for object size as the explanatory variable, the common geometrical quantity seems to be the area that the object covers. The existing study, however, reports that the visual perception of object size will change by the type of object shape even if the object area is the same [9]. Considering this finding, rectangular objects may cause different visual perception if their areas are the same but the aspect ratios are different. We made many samples as shown in Fig. 2 whose areas are the same but aspect ratios are different, and then we studied the visual perception of those object. As a result, we obtained that the width and height of object tend to affect the visual attention. We, therefore, supposed that width and height would be effective parameters for visual attention to rectangular objects and carried out an experiment for formulating the feature visual attention by object size using these two parameters.

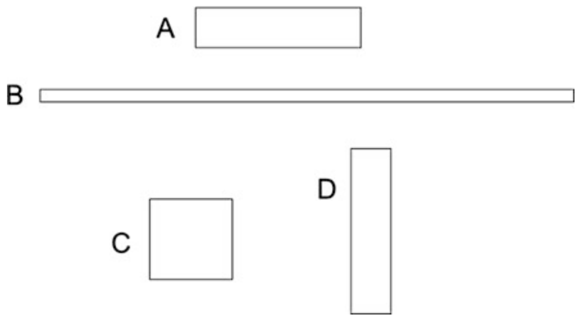


Fig. 2 *Rectangular* objects whose areas are the same but aspect ratios are different

4 Experiment

4.1 Experimental Condition

We used the visual angle as the unit of width and height. The visual angle is a unit to express length of line considering the distance between the screen and the user. According to the object size frequently used in the screens of business systems, we chose the minimum length of experimental condition as one degree and the maximum length as nine degrees. From a preliminary-test with the samples, we found the comparing different object length is easy if there is a difference more than one degree, and we set up nine conditions from one to nine degrees by one degree interval both in width and height. We thereby prepared 81 conditions of object size by combining different width and height. These objects have different the areas and the aspect ratios. For controlling the effects of color, we set the background color and object color as monotone, the luminosity of background at 230 and of object at 127.

4.2 Task

As the experimental task, the participants evaluated the visual attention of the left object (the target object) on the screen referring to the right object (the standard object) after the two objects were displayed in parallel. Figure 3 shows an example of the experimental screens. We chose an object of 5° both in width and height as the standard object, because the object is expected to have the medium value of visual attention among the samples. The layout and the distance of the standard object and the target object were not changed through the experiment. We kept the two objects inside the effective visual field so that the visual attention of the participants will never shift to the outside of visual field.

In the experimental task, the participants answered visual attention value of the target object with a natural number from one to nine assuming the visual attention

Fig. 3 Example of the experimental task screens

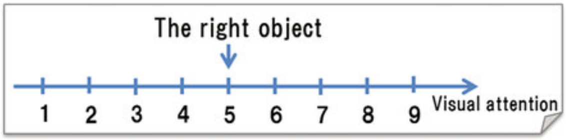


Fig. 4 The answer form which was indicated to the participants

value of the standard object was five. They input their answer with a key. Figure 4 shows the answer form indicated to the participants during the experiment so that they could check visual attention value of the standard object any time. Each participant evaluated all of the 81 experimental conditions. We changed the task order for different participants randomly.

4.3 Participant and Environment

Twelve males and six females from 20 to 50s of age participated in this experiment. Table 1 shows distribution of the participants in terms of gender and age. All of the participants ordinarily use computer screens in their business and are accustomed to operating keyboards.

In the experiment, we used a 50-in. plasma display. Its resolution was 1365 × 768 pixels. We set the visual distance between the screen and the participants 150 cm. The obtained result from this experiment is limited to the above environment.

Table 1 Distribution of participants in terms of gender and age

Age	Gender	
	Male	Female
20s	2	2
30s	5	3
40s	4	1
50s	1	0
Total	12	6

4.4 Instruction

We explained the objective, task, and timetable of the experiment to the participants with instruction documents. As instructions, we asked the participants to evaluate the visual attention to the target objects referring to the standard object. We also explained that each interval along the scale on the answer form (Fig. 4) was the same.

Before the main experimental task session, the participants executed twenty tasks as practice in order to get used to the task of evaluation and operation. The participants who wanted to do additional practice executed the same tasks in a different order. In this experiment, one task required about three seconds on the average. We explained the objective, and the handling of obtained data and personal information to the participants before the beginning of the experiment in reference to the ethical guideline of the Human Interface Society. The only participants who had understood and agreed joined the experiment.

5 Result

In this section, we will show the results obtained from the experiment. At first, we show the result of relationship between object width or object height and visual attention value, and then, the optimal combination of explanatory parameters to formulate accurately the visual attention value by object size.

5.1 Relationship Between Vertical or Horizontal Visual Angle and Visual Attention

Figure 5 shows the graph plotting the average visual attention value of the all participants for each vertical visual angle. In Fig. 5, the x-axis and y-axis respectively correspond to the vertical visual angle and the visual attention value, and each series is corresponding to a single value of the horizontal visual angle.

Figure 5 shows that the evaluated visual attention value tends to increase when the vertical visual angle becomes larger. We obtained the similar trend if the x-axis is changed from vertical to horizontal visual angle. Figure 5 also shows that the difference of visual attention value among different horizontal visual angel is little if the vertical visual angle is small but it is great if the vertical visual angle is large. This result means that there exists interaction between the vertical and horizontal visual angle. As a result, we will check that the vertical and horizontal visual angle and the interaction between them may affect the evaluated value of visual attention.

We performed variance analysis to check the effects of those parameters to the evaluated value of visual attention statistically. In the analysis, we used variance

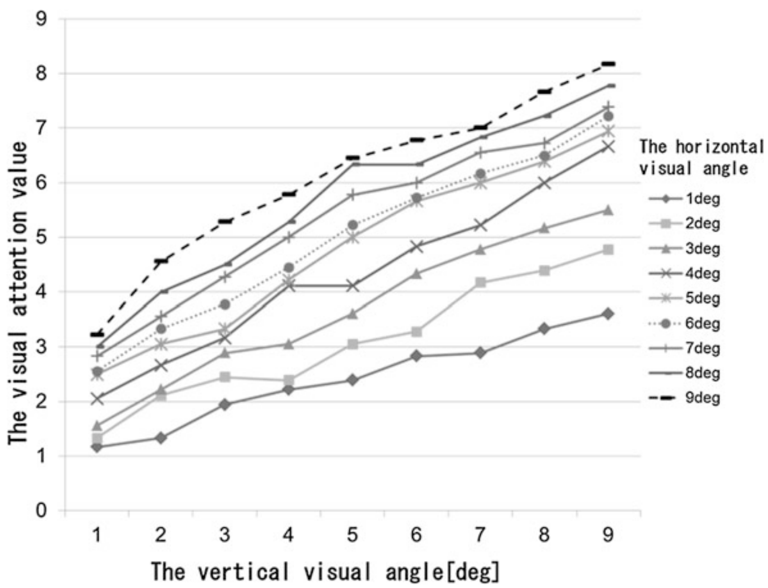


Fig. 5 The relationship between vertical visual angle and average evaluated value of visual attention

analysis of double-factor within-subject design with the data evaluated by all of the participants. Table 2 shows the variance analysis table.

According to Table 2, all of the vertical visual angle, horizontal visual angle, and interaction between them have a significant effect to the evaluated value of visual attention in a 0.1 % level. As the next step of analysis, we performed a simple main effect test, because interaction between vertical and horizontal visual angle has a significant effect. Firstly, we performed a simple main effect test of vertical visual angle and obtained the result that the difference among any group of vertical visual angle is significant. (In the order of horizontal visual angle which is 1°, 2°, 3°, 4°,

Table 2 The variance analysis table of double-factor within-subject design

Factor	Sum of square	DOF	Mean square	F-value
Individual (S)	181.0	17	10.65	
Vertical visual angle (A)	2560.4	8	320.1	211.9***
Residual S*A	205.4	136	1.5	
Horizontal visual angle (B)	1950.6	8	243.8	194.1***
Residual S*B	170.9	136	1.26	
Interaction A*B	116.0	64	1.81	3.484***
Residual S*A*B	566.1	1088	0.52	
Total	5750.4	1457		

*** $p < 0.001$, ** $p < 0.01$, * $p < 0.05$

Table 3 The variance analysis table of experimental condition and individual

Factor	Sum of square	DOF	Mean square	F-value
Experimental condition	4627.0	80	57.84	83.46***
Individual	181.0	17	10.65	15.36***
Residual	942.4	1360	0.69	
Total	5750.4	1457		

*** $p < 0.001$, ** $p < 0.01$, * $p < 0.05$

5°, 6°, 7°, 8°, 9°, F(8, 136) value is 22.9, 44.07, 55.87, 98.02, 83.89, 67.69, 70.03, 55.19, 48.56, where any F-value is $p < 0.001$). Secondly, we performed a simple main effect test of the horizontal visual angle and obtained the result that the difference among any group of horizontal visual angle is significant. (In the order of vertical visual angle which is 1°, 2°, 3°, 4°, 5°, 6°, 7°, 8°, 9°, F(8, 136) value is 20, 39.25, 47.41, 95.1, 73.37, 57.35, 44.26, 36.67, 45.59, where any F-value is $p < 0.001$). From those results, we found all of the vertical visual angle, horizontal visual angle, and interaction between them have a significant effect to the evaluated value of visual attention.

We performed other variance analysis whose factors are experimental condition and individual to check whether the differences among individuals are statistically significant. Table 3 shows the result of analysis. The effects from both the experimental condition and individuals are significant in a 0.1 % level. The result that individual effects are significant means each average evaluation value of the participants is different significantly. Namely, in the experiment, some participants evaluated relatively high and others relatively low.

5.2 Formulation of Effect of Size to Visual Attention

According to the previous section and Table 2, we obtained the result that all of the vertical visual angle, horizontal visual angle, and interaction between them have a significant effect to the evaluated value of visual attention by object size. In this section, we try to find the optimal combination of explanatory parameters to formulate visual attention value.

We set the average value of visual attention as the objective variable and set the vertical visual angle, horizontal visual angle, and interaction between them as candidates of explanatory parameters. Under this assumption, we performed multiple regression analysis, and found the combination of explanatory parameters where the accuracy estimation is the highest according to AIC and adjusted R-square. Table 4 shows the AIC value and adjusted R-square value in each combination of explanatory parameters.

AIC is a measure of the relative quality of statistical models for a given set of data. It is known that AIC of a better model is smaller. Table 4 shows that the

Table 4 AIC and adjusted R-square for combinations of explanatory parameters

Combination of explanatory parameters	AIC	Adjusted R-square
– Vertical visual angle	264.75	0.54
– Horizontal visual angle	286.57	0.40
– Vertical visual angle	69.43	0.96
– Horizontal visual angle		
– Vertical visual angle	68.84	0.97
– Horizontal visual angle		
– Interaction between vertical and horizontal visual angle		

combination whose AIC is the smallest is "vertical visual angle, horizontal visual angle, and interaction between them." Adjusted R-square is another measure of accuracy of models, and it is larger with a better model. Table 4 shows that the adjusted R-square is the largest with a combination of "vertical visual angle, horizontal visual angle, and interaction between them."

In this way, we found that the combination of vertical visual angle, horizontal visual angle, and interaction between them was optimal. Here, the interaction between vertical and horizontal visual angle means the area of rectangle. This result, therefore, suggests that visual attention to a rectangular object can be formulated by those parameters. To avoid multicollinearity problem [10] caused by supposing interaction terms, we used centering variables. The following Formula explains the feature visual attention by object size as a function of vertical visual angle, horizontal visual angle, and interaction between them. The coefficient of each explanatory parameter was obtained by multiple regression analysis (where, w1, w2, and w3 are coefficients, and C is a constant).

$$\begin{aligned}\text{Feature visual attention value to size} = {} & w1 * (\text{vertical visual angle}) \\ & + w2 * (\text{horizontal visual angle}) \\ & + w3 * (\text{vertical visual angle} * \text{horizontal visual angle}) + C\end{aligned} \tag{2}$$

5.3 *Comparison of Accuracy with the Existing Model*

In this study, we have supposed that we can formulate the effects of object size on the visual attention with the width and height of object that are simpler parameters than pixel position if the object shape is rectangle, and we carried out an experiment to verify the hypothesis. As a result, we obtained that the width and height are effective parameters for formulating the effects of objects size on the visual attention. We will here verify the accuracy of proposed model for visual attention by comparing the obtained results with those obtained with the existing model based on pixel positions.

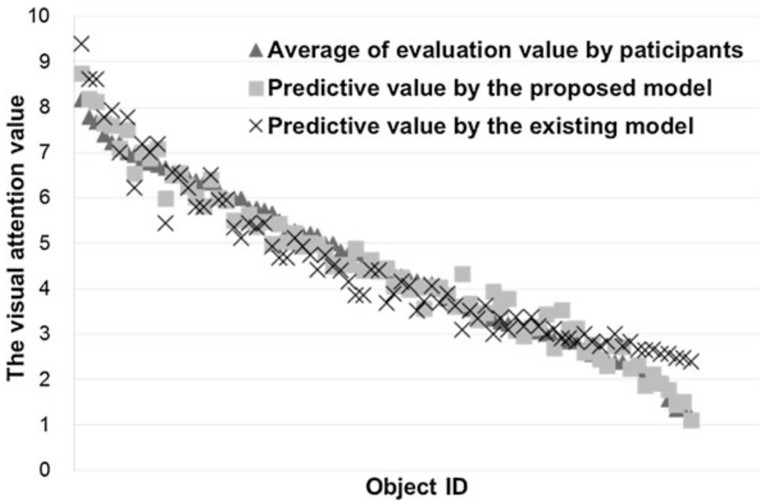


Fig. 6 The relationship between vertical visual angles and evaluated value of visual attention

When we calculated the visual attention value by the existing model of Eq. (1), we set the point-of-regard at the center of the target object. Figure 6 shows the value of predicted by proposed model with a symbol ■ and the existing model with a symbol ×, and the average values evaluated by the experiment with a symbol ▲.

According to Fig. 6, both the proposed and existing model can predict the average value evaluated by participants with a high accuracy. For evaluating the prediction accuracy of the proposed and the existing model, we compared with the two model using adjusted R-square and root mean square error (RMSE). Table 5 shows the result of comparison.

Comparing the adjusted R-square value and RMSE value between the existing and the proposed model in Table 5, the adjusted R-square value of the existing model is 0.9071, and that of the proposed model is 0.9699. On the other hand, the root mean square error of the existing model is 0.5395, and that of the proposed model is 0.3035. Therefore, we obtained that the accuracy of the both models is similar. Visual attention value of object size, however, can be formulated with simple input parameters namely the width and height of an object rather than microscopic parameters of pixel locations.

Table 5 Accuracy of each model (input parameters) against the average of evaluated value

Type of model (input parameters)	Adjusted R-square	Root mean square error (RMSE)
The existing model (Pixel)	0.9071	0.5395
The proposed model (width and height)	0.9699	0.3035

6 Discussion

6.1 *Analyzing Effects of Vertical or Horizontal Visual Angle to Visual Attention*

We analyzed the obtained data to clarify which length, namely width or height, affects more on visual attention. The coefficient value of the proposed model (Formula 2) reflects the degree of effects on visual attention because the range of values of vertical and horizontal visual angle in this experiment is the same. We compared the coefficient of vertical visual angle $w1$ with that of horizontal visual angle $w2$ and found that $w1$ is larger than $w2$. From this result, the vertical visual angle has a greater effect to visual attention value than the horizontal visual angle. To study the trend more in detail, we performed multiple regression analysis by each participant. In the analysis, we used the evaluated value of visual attention as the objective variable, and the vertical and horizontal visual angle as explanatory variables. In the result, the coefficient value of vertical visual angle is larger than that of horizontal visual angle among the fifteen participants. This result means that most of the participants seemed to be affected more by the vertical visual angle rather than by the horizontal visual angle when they evaluated visual attention by object size.

It is said that perception of object length is affected by layout (Flick's illusion [11]). This illusion is that vertical length seems longer than what it actually is when two objects are arranged side by side on the screen. On the other hand, horizontal length seems longer than what it actually is when two objects are arranged one above the other. In the experiment, the standard object and the target object are arranged side by side on the screen. We guess this arrangement caused the result that the vertical visual angle affects to the visual attention value more than the horizontal visual angle. We need to check this possibility by another experiment under the condition that two objects are arranged one above the other.

6.2 *Strategy for Effects of Individual Difference*

According to Sect. 5.1, the evaluated data obtained by the experiment varied among different individuals. We carried out this experiment under a controlled experimental environment, instructions, and practice task, but the effect of individuals was significant. This suggests that sensory perception for visual attention is varies in different individuals. For the future work, we have to discuss how to handle such an effect of individual variance.

One of possible strategies is that we prepare and show the evaluation result of visual attention not only with an average but also with minimum and maximum values. We expect that the model becomes more useful if the developers can select the type of output values based on the situations and conditions of design such as supposed user type and objective of usability evaluation. To prepare many kinds of output, we have to obtain more data. To get additional data, we have to try a bootstrapping method that is a statistical analysis method for reusing old data. Development of the model using the method is one of the future works.

7 Conclusion

The objective of this study was to develop a visual attention model that quantifies human sensory perception for visual attention in order to help the developers to evaluate screen design. If applying the model to the screen design evaluation, the parameter of the model was too microscopic for developers to adjust object size for appropriate visual attention. We, therefore, quantified and formulated the visual attention by object size based on more aggregative and simple parameters than pixel positions which are used by the existing model. We carried out an experiment with 18 participants for quantifying the effects object size on visual attention. The experimental results can be summarized as follows.

- Human sensory perception for visual attention to a rectangular object is quantified and formulated by the width and height of the object.
- The formulation whose input parameters are the width and height of a rectangular object can predict visual attention value with an accuracy similar to the existing formulation based on pixel positions of an object.

The obtained data by the experiment had variations among different individuals. In the future works, we have to discuss some strategies for handling the effect of individual variance, and we would like to verify the accuracy of the model on screens of real business systems for developing a practical visual attention model.

References

1. Ministry of Land, Infrastructure, Transport and Tourism: The guideline for prevention from human error accidents. http://www.mlit.go.jp/sogoseisaku/safety/yobo_guideline.pdf. Accessed Feb 2016 (in Japanese)
2. Reason, J.: Human Error. Cambridge University Press, New York (1990)
3. Norman, D.A.: The Psychology of Everyday Things. Basic Books, New York (1988)
4. Yokomizo, H., et al.: Quantification of visual attention (1)—modeling effect of color. In: HI Symposium 2013 (2013) (in Japanese)
5. Yoshida, H., et al.: Quantification of visual attention (2)—modeling effect of size, layout, and integrated elements. In: HI Symposium 2013 (2013) (in Japanese)
6. Tanaka, S., et al.: An attractiveness evaluation model based on the physical features of image regions. IEICE A JPN edition, J83-A(5), 576–588 (2000) (in Japanese)
7. Itti, L., et al.: A model of saliency-based visual attention for rapid scene analysis. IEEE Trans. Pattern Anal. Mach. Intell. **20**(11) (1998)
8. Feng-GUI: https://www.feng-gui.com/. Accessed 12 Feb 2016

9. Kim, H.J., et al.: Effects of shape and visual angle on area perception of geometrical figures. J. Japan Soc. Kansei Eng. **1**(1), 1–6 (2001) (in Japanese)
10. Farrar, D.: Multicollinearity in regression analysis: the problem revisited. Rev. Econ. Statist. **49**, 92–107 (1967)
11. Prinzmetal, W.: Vertical-horizontal illusion: one eye is better than two. Percept. Psychophysics, **53**(1), 81–88 (1993)

Usability Testing of an Online Farming Investment Website

Alyssa Jean A. Portus and Paul Jason C. Flores

Abstract The Philippines, being a tropical country, is a main producer of several agricultural products. With the increasing trend on the use of the internet in businesses, an online farming investment scheme has been recently introduced in the country. The crowdfunding website allows potential investors to select the crops they wanted to invest on. Upon confirmation of investment, farmers plant the investors' selected crops. The profit after the sales of products is shared among the investors and farmers at the agreed terms. This research study would like to test the usability of the website to increase usability in terms of efficiency and effectiveness. The study would like to explore the website's problematic areas and their implication on the potential investors' behavior. Preliminary analysis suggests that the current website interface appearance may have affected the integrity of website. Moreover, the timeliness of the responses significantly affects customer satisfaction and the overall usability of the website.

Keywords Usability testing · Online investment · Agricultural product investment

1 Introduction

The Philippines is a tropical country where agriculture thrives very well. However, local farmers were one of the poorest sector in the country based on various government statistics. Through the latest advancement in information technology, the concept of online farming investment has recently emerged in the market. The integration of real-life farming business and e-commerce was made possible. This type of business allows farmers to gather capital fund their business.

A.J.A. Portus (✉) · P.J.C. Flores
University of the Philippines—Diliman, 1101 Quezon City, Philippines
e-mail: aaportus@up.edu.ph

P.J.C. Flores
e-mail: pauljasoncflores@gmail.com

M. Soares et al. (eds.), *Advances in Ergonomics Modeling, Usability & Special Populations*, Advances in Intelligent Systems and Computing 486,
DOI 10.1007/978-3-319-41685-4_17

The unfamiliarity of the website poses overwhelming reactions based on the feedback of site's guests and members of one of the first online farming businesses in the Philippines.

The newness of the selected website makes it hard for the business to attract potential investors, as much of them find the website's functions difficult to understand. This is manifested in the testimonials of the members and guests in the website's forum site.

In order to attract more investors to keep the business going, the management must create a good reputation to its customers especially that the primary means to communicate to them is through the website itself. In this way, they can be more competitive and even expand their business in terms of area of farms to plow. It must be noted that effective communication is one of the key factors in succeeding in business like this.

This study aimed to assess the usability of the selected farming investment website. Moreover, the study aimed to present valuable insights that can help the web designers improve their website's usability. The usability testing aims to promote easier information retrieval that is essential in building a good reputation to existing and potential investors.

To improve the website's effectiveness, efficiency and user satisfaction, this study aims to identify the following:

1. Basic operations of the website
2. Success rate and completion time per operation of the user
3. Common sources of errors of the users
4. Impressions of the user about the website
5. Areas for improvement

2 Methodology

2.1 Identification of Basic Operations

The identified basic operations of the site, aside from new account registration are:

1. Invest Task: Investing on to crops
2. Modify Investment Task: Modifying/Cancelling the investment
3. Check Previous Investments Task: Checking on the previous (past cycles') investment(s)
4. Check Account Balance Task: Identifying the investor's current account balance
5. Locate Product Information Task: Locating each crop's information (price, projected return on investment, etc.)

2.2 Preparation of Test Materials

The study employed a three-part usability testing strategy. The first part was the pre-testing—to screen participants and to determine their demographics and familiarity with the website. This was immediately followed by usability testing proper—to test the website's ease of use as demonstrated by the each participant's test output. In this part, scenario based tasks were provided to the participants based on the previously identified basic operations. Post-task questionnaires were handed to out to each participant after the end of each task. The third official part of the strategy was the post-testing activity to get each participant's overall impression towards the website. A supplementary activity was performed to get the impressions of most investors of the site by looking through the site's feedback/inquiry page. The last part added significant qualitative contribution to the study. Pre-testing, post-task, and post-test questionnaires were prepared prior to the start of usability testing.

2.3 Selection of Participants

Nine test users (six males and three females) were subjected to the think aloud method for evaluation as recommended by [1]. Two out nine participants were familiar with the website of interest. Six of them were prospective investors. Additionally, reviews from the full-pledged investors were also gathered to supplement the findings.

2.4 Usability Testing

To commence the usability testing proper, a pre-test questionnaire was given to each participant. Subsequently, an introduction of the website and the usability testing was provided. Afterwards, the task scenarios were given to the participants. The order of the task scenarios provided varied for each participant to minimize the effect of learning. The usability testing implemented a think-aloud strategy wherein the participants voiced out their expressions on the interface while the test was on-going. The tasks had to be performed (but not necessarily be accomplished) by the participants. The scenario-based procedure aimed to get the completion rate and completion time of each task to test the interface's efficiency and effectiveness. After each task was performed, a post-task questionnaire was handed out to each participant to assess their impression on the interface in terms of their level of satisfaction. After the tasks were performed, each participant was asked to answer a post-test questionnaire—the System Usability Scale (SUS)[1] [2]. Lastly, each participant was asked to choose five words to describe their experience using Product Reaction Cards[2] [3].

3 Results and Discussions

Out of the 118 words to choose from, these top words were chosen by the test users to describe their experience while performing the primary tasks on the website (Table 1).

From 45 words chosen (nine test users with five words per user), only eight (8) words had positive attributes while the remaining 37 words suggest the users' dissatisfaction on the site (Table 2).

The overall average SUS score for all nine participants is 32.22 points out of 100 points which is way below the neutral score 50. The result of SUS is consistent with that of the Product Reaction Cards. This goes to show that designers of the website still have a lot to improve on the interface.

3.1 Main Menu Dashboard

Most test users had a hard time primarily because the chosen words on the website do not match their expectations (Fig. 1).

User Control Panel. This serves as the main header for functions such as User Home, Message Centre, Investment Requests and Invest for 10th cycle. The phrase 'user control panel' seems too technical to be clicked intuitively to perform an investment. Three out of nine test users expect it to be more of an Account Setting/Options button where one can change the settings of the website or update his/her profile which was not the case at present.

[1]Digital Equipment Corporation, 1986.

[2]Developed by and © Microsoft Corporation. All rights reserved.

Table 1 Top descriptive words from product reaction cards

Descriptive words	Frequency*
Confusing	5
Annoying	4
Inconsistent	3
Time-consuming	3
Complex	2
Disconnected	2
Dull	2
Hard-to-use	2
Simplistic	2
Unattractive	2

*Maximum frequency is 9

Table 2 System usability scores

SUS statements	SUS ave. score*
1. I think that I would like to use this system frequently	2.775
2. I found the system unnecessarily complex	2.500
3. I thought the system was easy to use	3.050
4. I think that I would need the support of a technical person to be able to use this system	5.550
5. I found the various function in this system were well integrated	1.950
6. I thought there was too much inconsistency	3.900
7. I would imagine that most people would learn to use this system very quickly	3.325
8. I found the system to be very cumbersome to use	2.775
9. I felt very confident using the system	2.500
10. I needed to learn a lot of things before I could get going with this system	3.900

*The lowest possible SUS score is 0 while the highest possible score is 10. Those with low scores are those statements that need to be addressed immediately to increase the usability of the website

Fig. 1 Main menu dashboard. The figure showed the main menus of the website. The sub-menus under the User Control Panel were also shown

User Home. See Sect. 3.4.

Message Centre. Although there were no task focused on sending and/or retrieving messages, three out of nine test users still clicked this button, expecting to be able send an investment request there. Most users do not expect this button be included in the User Control Panel.

Investment Requests. This button allows members to see their investment requests (both the past cycle's investment and the present cycle's requests). Additionally, this button, when clicked, will allow the user to delete his/her present cycle request(s). Two out of nine participants found the task of deleting present requests difficult. Moreover, varied expectations came out with name of the button. Some user view it as requests of the member to the site administrator, others view it as requests of the administrator to the member/user. Some also thought that this is the button to be clicked when one wish to invest.

Invest in 10th cycle. Five out of nine participants found the task of locating the investment button to be difficult with completion time of 147.67 s on average. Eight out of nine test users were unfamiliar with the phrase "10th cycle" which was part of the "Invest for 10th cycle" button that leads to the investment page—one of the primary pages of the website. When asked to perform the "investing to crops" task, most users refuse to click on the Invest for 10th cycle button because they felt like it was only an additional option for them.

Although there was an additional "Invest in 10th cycle" button separate from the dashboard, all test users were not able to locate it because of small size and unnoticeable feature. All users claimed that since investing is one of the most important functions, if not the most important, there should be a separate, very noticeable button on the page for efficiency.

3.2 Invest Task

To invest, one must click "Invest in 10th cycle" button and he/she will be directed to the investment page where he/she will choose which crops to invest on. The difficulty in finding the investment page was described in the previous section. The users in the investment page raised questions during the execution of the task.

Multiple submission. At present, when one wishes to invest on three different crops, he/she has to submit his/her investment request three times (one per crop) which is not efficient.

Notary. Some users were unfamiliar with why is it optional.

Seven out of nine participants rated the functionality and trustworthiness of the website from poor to fair based on the investment task alone.

3.3 Modify Investment Task

To modify investment, one must delete his/her previous request upon clicking the Investment Requests button. After which, he/she should re-submit a new request.

The task took the nine test users an average of 70.44 s.

The present task was found to be inefficient since one must delete the previous investment first and then create a new investment request or vice versa. Users expected that all current investment requests were loaded into one page for efficiency with less buttons to click. The redundancy of information found in both Investment Request landing page and User Home landing page provides frustration and confusion among the test users.

Seven out of nine participants rated the functionality and trustworthiness of the website from poor to fair based on the investment task alone.

3.4 Check Previous (Product) Investment Task and Check Account Balance Task

Both tasks can be performed by clicking onto the User Home button. These task were quickly done since both were viewing tasks alone with completion time 34.89 and 21.83 s for checking previous investment and checking account balance respectively. Although the tasks seem to be easier than the rest, the test users claim that User Home do not make an intuitive option for this tasks. An "Investment Portfolio", according to the three users, which were online investors, would have been a more appropriate term instead of User Home.

3.5 Locating Product Information Task

Locating product information is one of the essential tasks before one should invest. However, this task took more than a minute, 86.67 s to be performed because it was not readily and easily noticeable in the site's home page. At its present design, the Our Products button is found at the lower part of the website.

After locating the product information, most users expect that they could easily proceed with investment especially when they already know which crops to invest on. However, the present feature does not allow a direct link from the Our Products page to Investment page.

3.6 Others

The test users were also able to observe the following:

1. **White space in the menu bar**. The white space creates an unusable space that can be used as placeholder of other menus that are essential to the users (e.g. Our Products).
2. **Bold Logout menu**. The Logout menu is highlighted (bold) as compared to others which appears to be more clickable than the rest. This attracts user to click on it immediately.
3. **Location of "Update My Profile" function**. This function appears to different pages of the website and occupies a large amount of space. The test users suggest that it should be included in the menu bar for easy access.
4. **Presence of Join Now button**. When the scenario-based tasks were presented, the users were already logged in as members of the website. However, the "Join Now" button used for registration is still found in the homepage and in other parts. This provides confusion to members.
5. **Tardiness of Feedback**. One of the main concerns of the current members is the timeliness of feedback from the administrators. In turn, many members and guests felt less confident on the investments made in the website.

4 Areas for Further Research

Further activities can be done to improve the website's usability. These include:

1. **Establishment of standard terminologies to be used**. Establishment and use of generally accepted terms in the website can help increase efficiency and effectiveness. Potential and existing investors may feel more confident if they are familiar with the words found in the website.
2. **Creation of a tutorial video that will orient potential investors on the operations**. The presentation of a tutorial video before a potential investor starts exploring the website will help reduce their apprehensions.
3. **Create a Frequently Asked Questions (FAQs) page**. At present, a forum community where in members and guests may ask or answer a question. A detailed and well section FAQs page will help potential and existing investors be more knowledgeable on the website.

Acknowledgments The authors would like to extend their gratitude to all the test users who provided valuable insights on this research.

References

1. Benedek, J., Miner, T.: Measuring desirability: new methods for measuring desirability in the usability lab setting (2002)
2. Brooke, J.: SUS—a quick and dirty usability scale (1986)
3. Hwang, W., Salvendy, G.: Number of people required for usability evaluation: the 10 ± 2 rule. Commun. ACM **53**(5) (2010)

Effect of Position: An Ergonomics Evaluation of Police's Wearable Equipment

Adedapo Ilori, Yueqing Li, Vishnu Mahesh and Brian Craig

Abstract The importance of wearable equipment in certain profession for the purpose of safety and communication cannot be overemphasized. However, the number, size and positons of these equipment raise questions concerning ergonomics and human factors. This study examines the effect of the police body camera in conjunction with the walkie-talkie speaker on the ergonomics of an active duty police officer. Two additional alternatives to the current set up were provided. Result showed a significant effect of position on task performance and workload. The research should give insights to other wearable equipment.

Keywords Human factors · Ergonomics · Wearable equipment · Body camera · Walkie-talkie

1 Background

Police departments across the US have adopted the carry-on of cameras, otherwise known as bodycam on some of their officers. The reason for that, according to popular opinion was based on integrity of the force and safety of the people. The body camera is a device that records activities of a police officer while on duty and has to be on the officer throughout his interaction with subjects both verbal and physical.

A. Ilori · Y. Li (✉) · V. Mahesh · B. Craig
Department of Industrial Engineering, Lamar Univerity, Beaumont, TX, USA
e-mail: yueqing.li@lamar.edu

A. Ilori
e-mail: ailori@lamar.edu

V. Mahesh
e-mail: vmahesh@lamar.edu

B. Craig
e-mail: brian.craig@lamar.edu

M. Soares et al. (eds.), *Advances in Ergonomics Modeling, Usability & Special Populations*, Advances in Intelligent Systems and Computing 486,
DOI 10.1007/978-3-319-41685-4_18

One other existing piece of equipment that forms an essential part of this study is the walkie-talkie. The importance of this device cannot be overemphasized: providing communication and safety to police officers. Beyond law enforcement, there's a large area of application for this piece of equipment including but not limited to sports, recreation, tourism, port management and transportation.

These two devices of interest as miniature as they may appear can have an impact in the task performance, perception and general satisfaction of a potential user and for this reason, we decided to conduct experiments that simulate a basic activity of the police officer to see how much positioning of the devices may affect these factors.

Currently, both devices are independent of each other, the walkie-talkie is commonly placed on the shoulder and the bodycam is usually on the chest. We took these two natural positions into consideration and conceptualized a combined device that includes both the walkie-talkie and the bodycam. We then varied the positions and conducted experiments to measure performances.

2 Literature Review

A decent amount of research has been done in the area of body worn equipment, not just for the police but for other occupations requiring safety, surveillance and communication. It is important to point out that most of these literatures consider the entire gear as a whole rather than individual components. Also, there's little to no study that includes the body camera into this entire body armor. Likewise, no studies have been found to show the likely effects of long-term reporting of incidents into a speaker that requires the head to be turned into an unnatural position.

Ramstad et al. [1] demonstrated how load bearing vests worn by police officers reduce the range of motion in the trunk, pelvis and hip joints. Their experiment considered the subject under three different conditions; wearing no equipment, wearing a standard issue vest and finally wearing a load bearing vest.

Prior to that, Dempsey et al. [2], showed how the use of body armor significantly decreases performance and completion time of a law enforcement officer during different kinds of activities. Also, they claimed that mobility was greatly reduced in specific tasks and this "resulted in greater physiological effort".

Knight and Baber [3] developed an aid to help designers better assess the usability of wearable computer equipment. In their study, they developed a tool which measures the comfort of wearable computer equipment in terms of "emotion, attachment, harm, perceived change, movement, and anxiety." Generally, the wearable equipment described in their work are such that go on the head, arm, and hand and across the chest.

The bodycam is observed to be worn mostly on the chest, as is the case in the officers of most police departments across the country including those from our focus group. This particular design has a shape that is just slightly smaller than the regular smartphone. However, Mateescu et al. [4] stated in their work that an entire scene may not be captured by a bodycam on the chest. According to them, Cameras attached to the lapel of the uniform gives a better view with the risk of being easily knocked off while head mounts which may be located on helmets or sunglasses are most likely to pick up an officer's exact scene of view even when the officer turns only the head.

This study looks to achieve an optimal design and positioning of the bodycam/walkie-talkie which would comply with every possible human factor and fully support the ergonomics of the average police officer. Results and findings in this study may be applied to other occupations that have standardized wearable equipment.

3 Methodology

3.1 Focus Group

In the start of this study, we involved members of Lamar University Police department in a focus group. There were a total of 8 officers (6 males and 2 females). Their input and feedback to our survey questionnaires were used to design a moderate experiment. All the participants are used to the bodycam and wear it whenever they are on duty.

We created questionnaires to get information on their experiences with the bodycam. Information requested in the questionnaire involved demographics, user habit and user experience. This survey was created using Google forms. Also, we measured some anthropometric data which might have any influence results of our study. 2 out of our 8 focus group members claimed they aren't comfortable with the size of the camera while 5 participants complained about the positioning. 50 % claimed their camera has fallen of while they were on duty and also said they have the feeling at times that the camera is about to fall off; 6 out of the 8 claim they always have to adjust their cameras for comfort and safety reasons. A member of the focus group added the following comment to his survey response: "There's a considerable difference in where my seat belt lies whenever I'm driving with the camera on".

3.2 Experiment Participants

Six healthy male participants participated in the experiment. All participants were made to understand and sign an informed consent.

3.3 Apparatus

Bodycam: we measured the dimensions of a typical body worn camera and modelled a device that fits the same size.

Walkie-talkie speaker: we employed only the speaker component (the part that hangs from the shoulder) of a typical police walkie-talkie.

Combined device: We modelled a device that combines both a bodycam and walkie-talkie. This device was slightly heavier in weight than each device independently.

Questionnaires: A number of questionnaires were provided to all participants during this study. We created a survey for our focus group using Google Forms. After the experiment, we provided participants with subjective questionnaires, discomfort surveys and NASA Task Load Index.

Participants were also provided with shirts that fit the description of a police uniform and comfortable pants.

3.4 Independent Variable

For the purpose of this experiment, we identified the position of each of the devices as independent variable (Fig. 1).

(a) Position 1—Conventional Position (Speaker on the shoulder, Camera on the chest).
(b) Position 2—Combined device on the shoulder.
(c) Position 3—Combined device on the chest.

Fig. 1 Positions of the bodycam and walkie-talkie speaker

3.5 Dependent Variables

Task completion time (s): For each trial, we recorded how long it took a participant to move throughout the course from start to finish.

Workload: Using the NASA Task Load Index, we were able to measure the workload for each participant during each single trial.

Discomfort: At the end of each trial, the participant was asked to fill out a subjective questionnaire that indicated the level of discomfort associated with the different experiment conditions.

3.6 Experiment Task

The experiment task is a simulation of a police officer involved in a suspect foot chase. For each individual trial, participants will chase a suspect around a course that has 5 turns (2 right turns, 2 left turns and finally a right turn). At each turn, participants are required to report the following sentences into the walkie-talkie (Fig. 2):

1. Suspect has taken a turn; I am in pursuit.
2. Suspect is not armed, not dangerous.
3. Suspect is not accompanied by anyone.

Fig. 2 Reporting posture between different positions

3.7 Procedure

To enable to simulate a practical activity of an active duty police officer that is likely to provide a visible result in the existence or absence of a bodycam and an embedded device with a bodycam and a walkie-talkie, we would employ regular joggers/runners for our experiment task.

Three simulated devices were used for the experiment; a bodycam, a walkie-talkie and a device that combines both. Each participant was provided with a shirt that fits the dimension of a regular police uniform. Three positions were identified for placing the devices; first is having the camera on the original position which is at the center of the chest as seen on Lamar police officers while the walkie-talkie is on the shoulder, second position was to place the hybrid device on the shoulder while the third was placing the same hybrid device on the chest.

For each position, participants conducted two trials. Tasks were completely randomized. Participants were required to run a certain predetermined route. While running, they were required to give reports by speaking into walkie-talkie.

Questionnaires were provided to participants after each task to determine the level of comfort and the mental and physical perception of each task set up. Each session lasted between 15 and 30 min depending on the endurance and energy levels of each participant.

4 Result

ANOVA was conducted to analyze the performance data. Table 1 summarized the significance effect for performance measures:

4.1 Task Completion Time

The analysis revealed a significant main effect of position ($F_{2,\ 10} = 6.75$, $p = 0.0140$). Participants spent significantly less time with position 3 ($M = 62.33$, $SD = 5.75$) than that with position 2 ($M = 74.33$, $SD = 15.42$) and position 1 ($M = 80.17$, $SD = 21.07$). However, the task completion time with position 1 and 2 was not significantly different.

Table 1 Significant effect for performance measures

Dependent variables	Effect	F-Value	p-Value
Task completion time	Position	6.75	0.0140
Workload	Position	26.31	<0.0001

4.2 Workload

The analysis revealed a significant main effect of position ($F_{2,\ 10} = 23.61$, $p <$ 0.0001). Participants had significantly smaller workload with position 3 ($M = 4.28$, $SD = 1.18$) than that with position 2 ($M = 6.11$, $SD = 1.23$) and position 1 ($M = 7.00$, $SD = 1.30$). The workload between with position 1 and 2 was also significantly different.

4.3 Discomfort

All participants reported certain level of discomfort with position 1 and 2 after finishing the task. No discomfort was reported with position 3.

5 Discussion

5.1 Effect of Position on Task Completion Time

A significant main effect of equipment position on completion time was found (p = 0.014). Position 3 (combined device on the chest) mostly led to noticeably shorter finishing time, followed by position 2 (combined device on the shoulder). The conventional position yielded the lowest performance. The differences in completion times were significant between positions 1 and 3 (p = 0.0048) and between positions 2 and 3 (p = 0.0358). However, the difference in completion times were not significant between positions 1 and 2 (p = 0.2659). This could be attributed to the fact that reporting using a chest mounted device leads to better overall visibility for the participants when negotiating curves. A combined shoulder-mounted device can inhibit attention levels and visibility at corners leading to time lost at corners. The conventional position elicited the highest completion time since the inherent low visibility while reporting around the corner was coupled with the participants' concern for the device falling off.

5.2 Effect of Position on Workload

The result showed that combining the equipment has a significant effect on workload as well (p < 0.0001). Multiple comparison tests revealed that the differences in discomfort levels were significant among all the positions, most notably between positions 1 and 3 (p < 0.0001) and between positions 2 and 3 (p < 0.0007). Participants largely felt they needed a lot less mental effort while working with a combined device than with the devices separate. This could be due to the fact that combining the device serves to eliminate one device. In a very dynamic activity as a foot chase or a patrol, the larger the number of devices attached, the larger will be the individual's impression of perceived task load. The performance might also be affected due to the subjects discreetly being cautious about the devices falling off during the activity. The result of NASA TLX work load justifies the result of task completion times for various positions.

5.3 Effect of Position on Discomfort

Discomfort survey revealed differences in discomfort levels between equipment positions. Position 3 was found to be significantly better over the other two positions. Position 3 also had the advantage of an ergonomically better neck position suited for the reporting task. Reporting in position 3 required flexion of the neck mostly less than 30 degrees. This is considerably lower than the normal range of joint motion for neck of 70–90°. Positions 1 and 2 however require the participants to combine flexion with lateral rotation of the neck. The lateral rotation in this case falls between 60° and 90° which is close to the upper limit of normal range of motion. Combination of lateral rotation with flexion, higher physical exhaustion and mental stresses may expose the police officers working on positions 1 and 2 to a higher risk of neck injuries due to the excessively strained position of the sternocleidomastoid muscle (SCM) which are the main muscles involved in tilting and rotation of head. SCM is vital to relaying the brain the orientation of the head with respect to the body and hence injuries due to sudden stretching or frequent exertions can potentially lead to trigger points in this muscle. The results can be a wide variety of symptoms that includes dizziness, blurred vision, disorientation and nausea.

A chest mounted device not only reduces the risks of neck injury compared to shoulder mounted one but also provides an overall better field of view at all times and significantly improved situational awareness in constrained spaces and corners. Furthermore, it is intuitive that the conventionally adopted position for the speaker on the right shoulder might significantly reduce the pace, attention and situation awareness of police officers especially in a foot-chase scenario when negotiating leftward turns. Position 3 (combined device on the chest) however is optimized to be used for either way.

6 Conclusion

This study is intended as a preliminary investigation of the discomfort level and task performance associated with wearable equipment for police officers of three different configurations. The result showed a significant main effect of position on task performance and workload. The study should provide insights to wearable equipment in applications beyond security. There are however some limitations associated with the research. As a preliminary study, the sample size was small. To improve the power of the experiment, larger sample size should be recruited. Also, all the participants were male and hence the effect of gender was not examined.

References

1. Ramstrand, N., Zügner, R., Larsen, L., Tranberg, R.: Evaluation of load carriage systems used by active duty police officers: relative effects on walking patterns and perceived comfort. Appl. Ergon. **53**, 36–43 (2016)
2. Dempsey, P., Handcock, P., Rehrer, N.: Impact of police body armour and equipment on mobility. Appl. Ergon. **44**, 957–961 (2013)
3. Knight, J., Baber, C.: A tool to assess the comfort of wearable computers. Hum. Factors **47**, 77–91 (2005)
4. Mateescu, A., Rosenblat, A, Boyd, D.: Police body-worn cameras. http://www.datasociety.net/pubs/dcr/PoliceBodyWornCameras.pdf (2015)
5. Coca, A., Roberge, R., Williams, W., Landsittel, D., Powell, J., Palmiero, A.: Physiological monitoring in firefighter ensembles: wearable plethysmographic sensor vest versus standard equipment. J. Occup. Environ. Hyg. **7**, 109–114 (2009)
6. Smith, D., Haller, J., Dolezal, B., Cooper, C., Fehling, P.: Evaluation of a wearable physiological status monitor during simulated fire fighting activities. J. Occup. Environ. Hyg. **11**, 427–433 (2014)
7. Lewinski, W., Dysterheft, J., Dicks, N., Pettitt, R.: The influence of officer equipment and protection on short sprinting performance. Appl. Ergon. **47**, 65–71 (2015)
8. Orr, R., Poke, D., Stierli, M., Hinton, B.: The perceived effect of load carriage on marksmanship in the tactical athlete. J. Sci. Med. Sport **19**, e92 (2015)
9. Pirsiavash, H., Ramanan, D.: Detecting activities of daily living in first-person camera views. In: IEEE Conference on Computer Vision and Pattern Recognition (CVPR), 2012 (2012)
10. Carlton, S., Orr, R., Stierli, M., Carbone, P.: The impact of load carriage on mobility and marksmanship of the tactical response officer. In: Australian Strength and Conditioning/Tactical Strength and Conditioning Conference (2013)

Relationship Between the Complexity of System Functions and Amount of Displayed Information on a Mobile Device with Touch Display

Suguru Ito, Masahiko Sakata, Munenori Koga, Daisuke Iizawa and Miwa Nakanishi

Abstract Multifunctioning systems are being extensively used in households these days. System information is summarized on a portable terminal. Users benefit from the value produced by multifunctional systems. Therefore, it is conceivable that the motivation to use such systems can increase or decrease depending upon the balance between the amount of information on the terminal screen and the amount of system information. Additionally, the elderly are assumed as next-generation users. Thus, in this study, from the viewpoint of motivating the elderly, we explore the relationship between the amount of information on the terminal screen and the amount of system information. As an experiment, we create a smartphone application that can control the amount of information, and the participants performed a task in which varying amounts of information were combined. As a result, a relationship between the amount of information on the terminal screen and the amount of system information was found.

Keywords Mobile device · Amount of information · Motivation

S. Ito (✉) · M. Nakanishi
Graduate School of Science and Technology, Keio University, Yokohama, Japan
e-mail: i.suguru1009@gmail.com

M. Nakanishi
e-mail: miwa_nakanishi@ae.keio.ac.jp

M. Sakata · M. Koga · D. Iizawa
Mitsubishi Electric Corporation, Tokyo, Japan
e-mail: Sakata.Masahiko@bk.mitsubishielectric.co.jp

M. Koga
e-mail: Koga.Munenori@dx.MitsubishiElectric.co.jp

D. Iizawa
e-mail: Iizawa.Daisuke@df.MitsubishiElectric.co.jp

M. Soares et al. (eds.), *Advances in Ergonomics Modeling, Usability & Special Populations*, Advances in Intelligent Systems and Computing 486,
DOI 10.1007/978-3-319-41685-4_19

1 Introduction

Multifunctioning systems are being extensively used in households these days. In addition, mass production of mature products is being standardized and equalized globally. Therefore, Japanese companies must focus on stimulating consumer motivation to buy multifunctional products in order to compete with cheap and monofunctional products manufactured in foreign countries.

System diversification is a global trend. Simultaneously, interfaces are facilitating digitization and miniaturization. Portable touch devices will be used as integrative interfaces for multiple systems in the near future.

For the user, a hierarchical screen structure and the amount of information on the screen affect motivation as a medium for frequently using portable touch devices with limited screen size.

In addition, in terms of portable touch terminal usage trends, the smartphone penetration rate of the elderly population is increasing while that of the young population has reached a ceiling; therefore, the elderly can be a new target for the portable touch terminal market.

In this study, assuming that the user handles a multifunctional system with a small interface, we experimentally explore interface designs that can motivate the use of multifunctional systems. In particular, we have focused on the elderly as the target experimental group.

Specifically, we show the interface screen of a virtual system on a portable touch device and measure user behavior, cognition, and psychology using human factor techniques. We have revealed a relationship between the complexity of systematic functions, the amount of information on the interface, and the users' motivation to use the system.

2 Method

2.1 Diversity of the Purposes of Information Search

Today, information retrieval is performed with a clear purpose, such as route search, and is also performed without any purpose.

Information search is receiving significant attention regarding promotion of interest in products and services by utilizing the different types of information search.

In a previous study, Takahashi [1] identified purposeful information search and purposeless information search. Takahashi explored the role of information design for purposeless information search [1].

It is necessary to create interface design guidelines for both conventional purposeful and purposeless information searches.

In an experiment, we presented a task that divided the two types of information search between the participants.

2.2 Technology Acceptance Model

The technology acceptance model in the IT field explains the new technology acceptance behavior of a user.

It has been used to study user perspectives, e.g., relative to the adoption of IT products [2, 3].

Many expansion models have been proposed. In this study, we use the Unified Theory of Acceptance and Use Technology expansion model (UTAUT), shown in Fig. 1, to measure user motivation [4].

In UTAUT, the configuration concept of use motivation is equal to four concepts.

Performance expectancy: The degree to which an individual believes that using the system will help him or her to attain gains in job performance.

Effort expectancy: The degree of ease associated with the use of the system.

Social influence: The degree to which an individual perceives that important others believe he or she should use the new system.

Facilitating conditions: The degree to which an individual believes that an organizational and technical infrastructure exists to support use of the system.

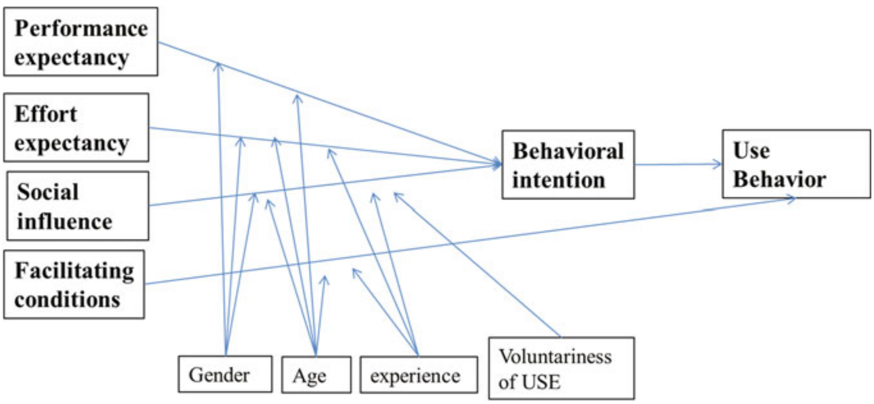


Fig. 1 The UTAUT model

2.3 Experimental Task

This experimental task was divided into the two types of information search. We instructed the participants as follows.

(A) You have to locate a certain keyword from among the applications.

(B) During task preparation, you can manipulate information freely within the application.

To relax participants during the non-target information search task, the sentence of the teachings of the (B) doesn't contain a nuance like experiment task.

According to (B), participants browse for two minutes in a non-target information search task using a smartphone (Android Galaxy Note Edge SC-01G, Samsung Ltd.).

After the free information search, participants began a search task to locate the indicated keyword. The task was performed for each condition according to a combination of different hierarchies, numbers of pages, and characters.

The experimental conditions were hierarchical structure (shallow and deep), total number of pages (50, 100, 150, and 200 pages), number of letters (200, 300, and 400 letters), and information search type (objective search and non-target search) (Figs. 2 and 3).

Measurement items were "time", "button touched," and "page transition," which were recorded in an operation log.

In addition, after completing each task, the participants answered a questionnaire based on the work by Venkatesh et al. The UTAUT model (Sect. 2.2) scores for performance expectancy, effort expectancy, social influence, and behavioral intention were recorded as subjective scores.

The questionnaire content is shown in Table 1.

Fig. 2 Screen layout (400, 300, and 200 letters from the *left*)

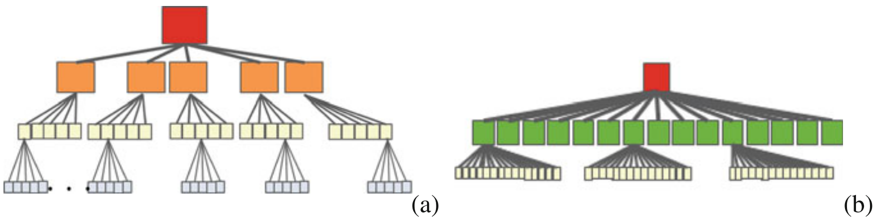


Fig. 3 **a** Deep hierarchical structure **b** shallow hierarchical structure

Table 1 Questionnaire

Concept	Question
Performance expectancy	I would find the system useful
	I would find the system joyful
Effort expectancy	My interaction with the system would be clear and understandable
	It would be easy for me to become skillful at using the system
Social influence	People who influence my behavior may think that the way to obtain knowledge using this system is very cool
	I would like to introduce this system to people who influence my behavior
Behavioral intention	I want to use this system again
	If there is such an app, I want to use

Participants and Ethical Considerations.

Thirty subjects over the age of 65 (male and female) participated in the experiment. In the experiment, we described the experimental procedure and obtained consent.

3 Results

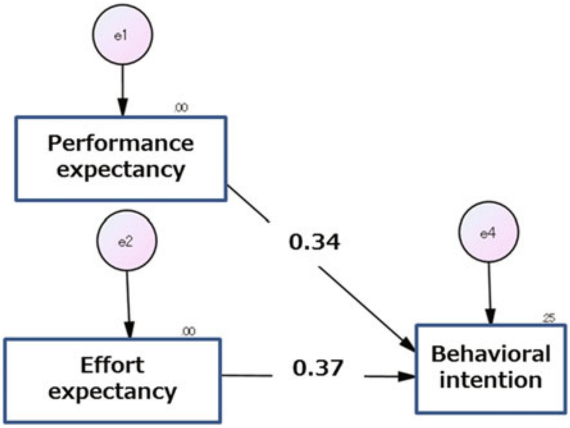
3.1 Purposeful Information Search

3.1.1 Structural Equation Modeling

To observe the impact of performance expectancy, effort expectancy, and social influence on behavioral intention, we used structural equation modeling using AMOS 17.0 (IBM Ltd.).

After creating a UTAUT path diagram, the GFI (Goodness of Fit Index) value, which is an indicator of interpretability, was 0.86. The fitness of the model is poor; thus, we recreated the path diagram without including social influence because its standardized coefficient was small.

Fig. 4 UTAUT path diagram



This resulted in a GFI value of 0.93; therefore, the fit of this model was acceptable. The UTAUT path diagram is shown in Fig. 4.

As seen in Fig. 4, the impact value for performance expectancy was 0.34 and that for effort expectancy was 0.37. We found that these factors similarly influence behavioral intention.

3.1.2 Subjective Scoring of UTAUT Items UTAUT

From the results given in Sect. 3.1.1, we focus on the subjective scoring of behavioral intention, performance expectancy, and effort expectancy. We analyzed the results using two-way factorial analysis of variance (ANOVA) without replication against a combination of hierarchical structures and number of letters.

First, we analyzed the results without replication against behavioral intention.

For 50 pages, a main effect was seen in the number of letters; however, interaction was also observed. Thus, we confirm a simple main effect using one-way factorial ANOVA. As a result, with the shallow structure, the subjective scoring with 400 letters was less than the score with 200 letters. With 200 letters, the subjective scoring with the deep structure was less than the score obtained using the shallow structure. No significant difference in the other conditions was observed (Fig. 5).

Then, we analyzed the results using two-way factorial ANOVA without replication against performance expectancy.

With 50 pages, a main effect was observed in the number of letters; however, interaction was also observed. Thus, we confirm a simple main effect using one-way factorial ANOVA. As a result, with 200 letters, the subjective scoring for the deep structure was less than that of the shallow structure. For the shallow structure, the subjective scoring with 400 letters was less than that of 200 letters.

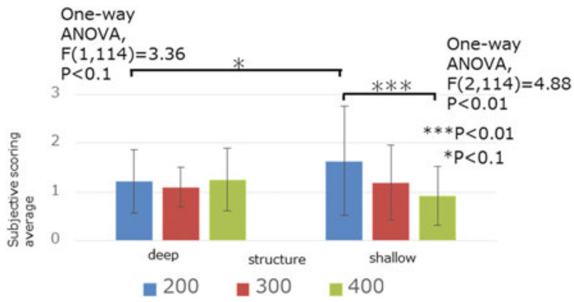


Fig. 5 Average subjective scores for behavioral intention with 50 pages

For 100 pages, a main effect was observed in the structure (Two-way ANOVA, F (1,114) = 3.82, $p < 0.1$). Therefore, we analyzed the results using Bonferroni multiple comparisons. As a result, a significant difference between the subjective scoring for the deep structure (less) and that of the shallow structure was confirmed.

With 150 pages, a main effect was observed in the number of letters; however, interaction was also observed. Thus, we confirm a simple main effect using one-way factorial ANOVA. As a result, with the deep structure, the subjective scoring with 300 letters was less than that of 200 and 400 letters.

With 200 pages, a main effect was observed in the number of letters; however, interaction was also observed. Thus, we confirm a simple main effect using one-way factorial ANOVA. As a result, for the shallow structure, the subjective scoring of 300 letters was less than that of 200 and 400 letters.

Then, we analyzed the results using two-way factorial ANOVA without replication against effort expectancy.

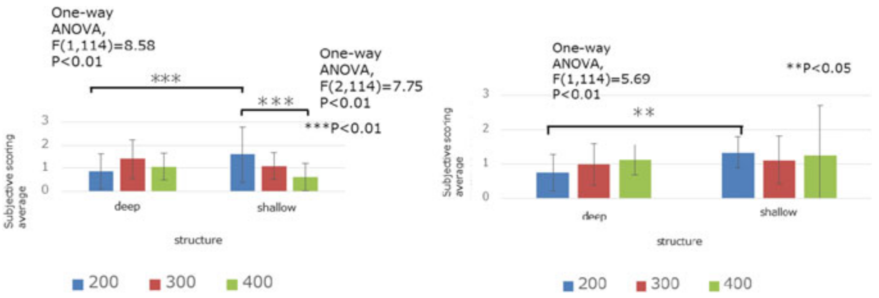
With 150 pages, a main effect was observed in the structure (Two-way ANOVA, F (1,114) = 3.23, $p < 0.1$); thus, we analyzed the results using Bonferroni multiple comparisons. As a result, a significant difference between the subjective score for the deep structure (less) and the score for the shallow structure was confirmed. No significant difference was observed for the other conditions (Figs. 6, 7 and 8).

3.2 *Purposeless Information Search*

3.2.1 Structural Equation Modeling

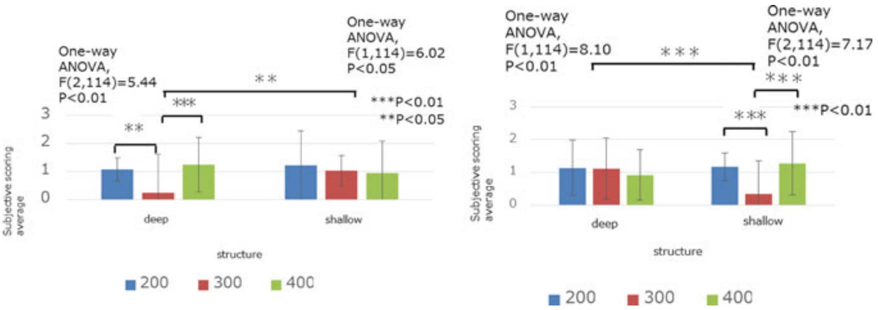
To observe the impact of performance expectancy, effort expectancy, and social influence on behavioral intention, we used structural equation modeling using AMOS 17.0 (IBM Ltd.).

After creating a UTAUT path diagram, the GFI value was 0.83. The fitness of the model was poor; therefore, we recreated the path diagram without including performance expectancy, whose standardized coefficient was small.



(a) (b)

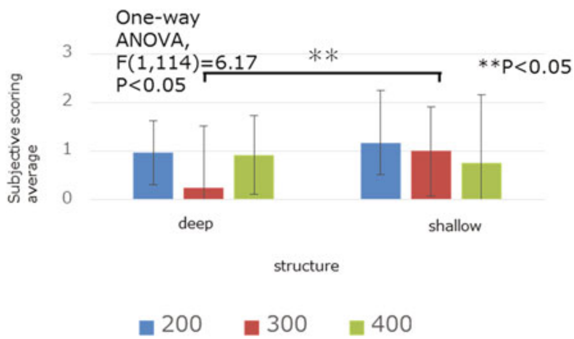
Fig. 6 Average subjective scores for performance expectancy with **a** 50 pages and **b** 100 pages



(a) (b)

Fig. 7 Average subjective scores for performance expectancy with **a** 150 pages and **b** 200 pages

Fig. 8 Average subjective scores for effort expectancy with 150 pages



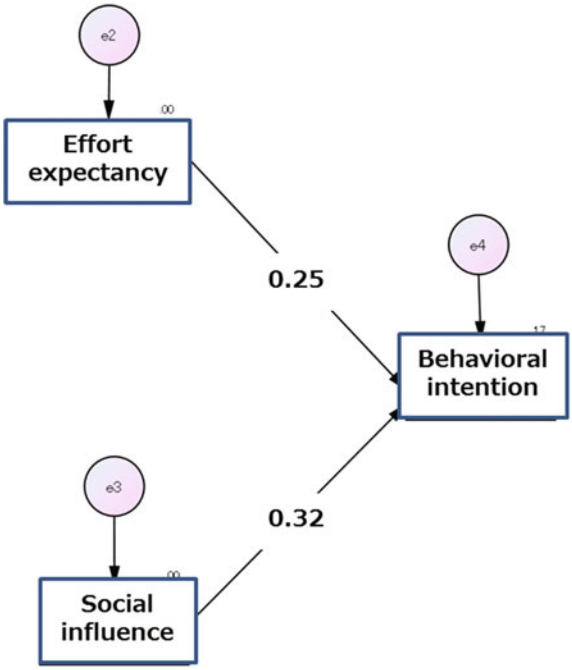


Fig. 9 UTAUT path diagram

The GFI value was then 0.95; therefore, the fit of this model was considered to be very good. This UTAUT path diagram is shown in Fig. 9.

Looking at the impact, the values for effort expectancy and social influence are 0.25 and 0.32, respectively. We found that social influence has a greater impact than behavioral intention.

3.2.2 Subjective Scoring of UTAUT Items UTAUT

From the results given in Sect. 3.2.1, we focus on the subjective scoring for behavioral intention, effort expectancy, and social influence. We analyzed the results using two-way factorial ANOVA without replication against a combination of hierarchical structure and number of letters.

First, we analyzed the results without replication against behavioral intention.

With 150 and 200 pages, a main effect was observed in the structure (Two-way ANOVA, $F(1,114) = 4.93$, $p < 0.05$) (Two-way ANOVA, $F(1,114) = 4.31$, $p < 0.05$); thus, we analyzed the results using Bonferroni multiple comparisons. As a result, a significant difference between the subjective scoring for the shallow structure (less) and that of the deep structure was confirmed. No significant difference was observed for the other conditions.

Then, we analyzed the results using two-way factorial ANOVA without replication against effort expectancy.

With 50 pages, a main effect was observed in the structure (Two-way ANOVA, F (1,114) = 4.55, p < 0.05); thus, we analyzed the results using Bonferroni multiple comparisons. As a result, a significant difference between the subjective scoring for the shallow structure (less) and that of the deep structure was confirmed. No significant difference was observed for the other conditions.

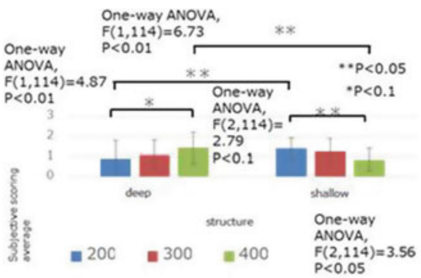
Then, we analyzed the results using two-way factorial ANOVA without replication against social influence.

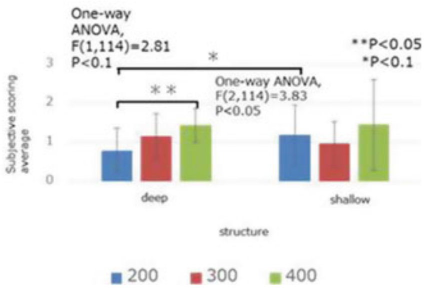
With 50 pages, no main effect was observed in the number of letters; however, interaction was observed. Thus, we confirm a simple main effect using one-way factorial ANOVA. As a result, for the deep structure, the subjective scoring of 200 letters was less than that of 400 letters.

With 100 pages, a main effect was observed in the number of letters (Two-way ANOVA, F (2,114) = 4.45, p < 0.05); thus, we analyzed the results using Bonferroni multiple comparisons. As a result, significant difference between the subjective scoring for 200 and 300 letters and the score for 400 letters was confirmed.

With 150 pages, no main effect was observed in the number of letters; however, interaction was observed. Thus, we confirm a simple main effect using one-way factorial ANOVA. As a result, for deep structure, the subjective scoring for 300 letters was less than the score of 200 and 400 letters.

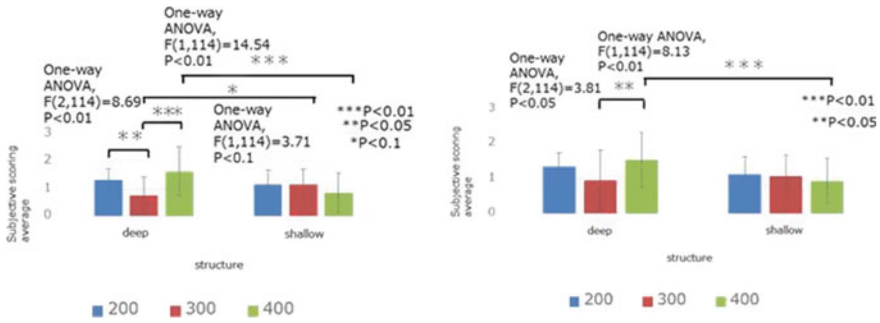
With 200 pages, a main effect was observed in the number of letters; however, interaction was observed. Thus, we confirm a simple main effect using one-way factorial ANOVA. As a result, for deep structure, the subjective scoring for 300 letters was less than that of 400 letters. In addition, for 400 letters, the subjective scoring for the shallow structure was less than that of the deep structure (Figs. 10 and 11).





(a) (b)

Fig. 10 Average subjective scores for social influence with **a** 50 pages and **b** 100 pages



(a) (b)

Fig. 11 Average subjective scores for social influence with **a** 150 pages and **b** 200 pages

4 Conclusion

In this study, we have considered the optimal balance between the complexity of systematic functions and the amount of information on an interface screen in order to maximize the elderly's motivation to use a system.

The results of structural equation modeling and two-way factorial ANOVA without replication are summarized in Tables 2 and 3 (× indicates significant difference; Δ indicates significant difference).

As can be seen in Table 2, for purposeful information search, it was found that performance and effort expectancies influence behavioral intention. In the case of deep structure and 400 letters, it was found that motivation is low.

Table 2 Summary of purposeful information search experiment

UTAUT item	Performance expectancy		Effort expectancy		Behavioral intention	
structure/letters	deep	shallow	deep	shallow	deep	shallow
200	×		×		×	
300	×	×	×		×	
400	×	×	×	×		×

Table 3 Summary of purposeful information search experiment

UTAUT項目	Effort expectancy		Social influence		Behavioral intention	
structure/letters	deep	shallow	deep	shallow	deep	shallow
200		×	×	×		×
300		×	×	×	Δ	×
400		×		×		×

As can be seen in Table 3, for purposeless information search, it was found that effort expectancy and social influence affect behavioral intention. In the case of shallow structure, it was found that motivation is low.

The results of this study can be applied to interface design for portable touch devices and websites using dividing information search form.

In future, it is necessary to consider the following problems.

- By using objective indicators, such as physiological indicators, we must consider it from the viewpoint of support for the results, and interests.
- We will conduct an experiment with different amounts of information on the terminal display.
- We will conduct an experiment with a new display that contains images and color as new parameters.
- We will quantify the amount of information on the terminal display and the amount of system information.
- We will create a model that can calculate motivation against the amount of information.

References

1. Takahashi, M.: A psychophysiological approach to purposeless information searching—Information design based on optimal stimulation level theory (2013)
2. Davis, F.D., Bagozzi, R.P., Warshaw, P.R.: User acceptance of computer technology: a comparison of two theoretical models. Manage. Sci. **35**(8), 982–1003 (1989)
3. Davis, F.D.: Perceived usefulness, perceived ease of use, and user acceptance of information technology. MIS Q. **13**(3), 319–339 (1989)
4. Venkatesh, V., Morris, M.G., Davis, G.B., Davis, F.D.: User acceptance of information technology: toward a unified view. MIS Q. **27**(3), 425–478 (2003)

Methodology of Digital Firearm Ergonomic Design

Marek Bures, Tomas Görner, Antonin Miller and Martin Kaba

Abstract This paper describes a methodological human centered approach during handgun design. For evaluation of reach distances to handgun controls (trigger, slide stop, magazine catch) a digital human models and ergonomic software were used. With these digital human models a variety of minimal, maximal and average reach distance for Americans, Europeans and Asians were proposed. Distances for American and European population were used for creation of a handgun functional sample. Test shooting performed with this functional sample was evaluated by a questionnaire which was filled by 18 male members of armed forces. These responses evaluated the suitability of functional sample and identified specific parameters for future improvement.

Keywords Handgun · Digital human models · Specific populations · Ranges · Grips · Virtual models

1 Introduction

Each tool used by a man need to be suitable for use and also designed in the way that doesn't endanger the user. The product ergonomics is the field that deals with those issues. This paper is mainly focuses on the field of firearms especially handguns. Mainly armed forces (army, police, etc.) come into contact with guns

M. Bures (✉) · T. Görner · A. Miller · M. Kaba
Department of Industrial Engineering and Management, University of West Bohemia,
Univerzitni 8, 30614 Pilsen, Czech Republic
e-mail: buresm@kpv.zcu.cz

T. Görner
e-mail: tgorner@kpv.zcu.cz

A. Miller
e-mail: amiller@kpv.zcu.cz

M. Kaba
e-mail: kaba@kpv.zcu.cz

M. Soares et al. (eds.), *Advances in Ergonomics Modeling, Usability & Special Populations*, Advances in Intelligent Systems and Computing 486,
DOI 10.1007/978-3-319-41685-4_20

nearly every day. For this reason these weapons must be adapted to fit in the hand in the best way. Also the firearms must be maximally reliable during shooting.

There are several areas of firearm design that have been the subject of previous researches. Hancock et al. [1] discussed the issues in firearms design. They stated that the need for ergonomics firearm improvement has never been greater. Among their observations, trigger pull, hand grips, sighting devices, and safeties are among the critical components of firearms whose ergonomics have not been studied, nor have their interfaces been standardized.

Previous studies regarding shooting performance have focused mainly on postural stability and its impact on shooting accuracy [2–5]. Several researchers investigated the effect of rifle length and weight on shooter stability. The concept of weight reduction in rifle design has long been emphasized. Larger aiming fluctuations occur with heavier rifles because heavier rifle weight increases upper extremity loading, which increases the center of pressure fluctuation of the shooter-rifle system in the transverse axis [6]. In addition, Kemnitz et al. [7] examined the effects of gender, rifle stock length (17.8, 22.3, and 26.2 cm), and rifle weight (3.2 vs. 3.8 kg) on military marksmanship performance. There were no significant differences in either measure of marksmanship performance as a function of sex. Marksmanship precision was significantly better with the lighter rifle. Results of [8] also revealed that reducing rifle weight was one of the most important factors of rifle redesign. Other researchers studied the influence of muscle tremor [9, 10] or felt recoil on shooting performance [11]. Results from all these studies showed that rifle design has an impact on posture and muscle activation. Designs that were heavier and longer caused more shooter fatigue during aiming and were significantly less-stable and less-preferred among participants.

Another area of discussion leads to configuration types. There is broad disagreement on whether a bullpup rifle configuration, which is typically lighter, shorter, and has its center of gravity located closer to the user, is objectively better or worse than a conventional configuration rifle from a usability and performance standpoint. From the studies of [6] and [12] according to the stability and performance analysis the bullpup weapon designs were found to provide a significant advantage, even while subjects showed considerable preference toward the conventional weapons.

Nearly all of the previous studies focus primary on rifles and so few studies have been performed on handguns. This paper focuses directly on handguns design however the principles and methodologies can be widely utilized also for the rifles. Also the importance of firearms operators isn't much discussed however Cornell et al. [13] focused on comparison of firearm safety mechanisms. The results from 30 experienced subjects showed that safeties whose actuators were mounted within easy reach of the trigger finger were preferred.

The objective of the paper is to present a methodology using human-centered design during the development stages of the new handgun model. Today the information technologies are perceived as an indispensable tool in the design of a new product. Possibility to verify product parameters and suitability for user in computer virtual reality before functional prototype is absolutely undeniable.

For this purpose a digital human models (DHM) are used to evaluate the suitability of the design according to anthropometric parameters of the users. These DHM are fully customizable, so that results of studies carried out are perhaps the most realistic. If we talk about customization of a DHM, we mean setting its gender, nationality, percentile or specific body measurements, so that our digital human as much as possible corresponds to specific user. With user defined like this we then have the possibility to perform a variety of ergonomic analysis. We can find out how users (from different population size) will perform a given task, analyze the risk of injury, needed power, reach, grips and many other factors.

2 Methodology

Standard progress in the new firearm development consist of two phases, prototype development and production preparation as described on Fig. 1. Our methodology supports the development phase.

Prototype development phase consist of three main activities. First there is a conceptual design. Within this activity the development team must firstly create a concept of the chosen solution supplemented with sketches, calculations and simplified assemblies. The second activity is a creation of functional sample. Technical implementation of the new product, which verifies principal solutions especially in terms of functionality of individual parts or all assemblies of the new product, is developed. Functional sample is made on the basis of the design documentation. Construction, design, and material integrity may differ from the final product. The third and last activity in development phase is the creation of the prototype.

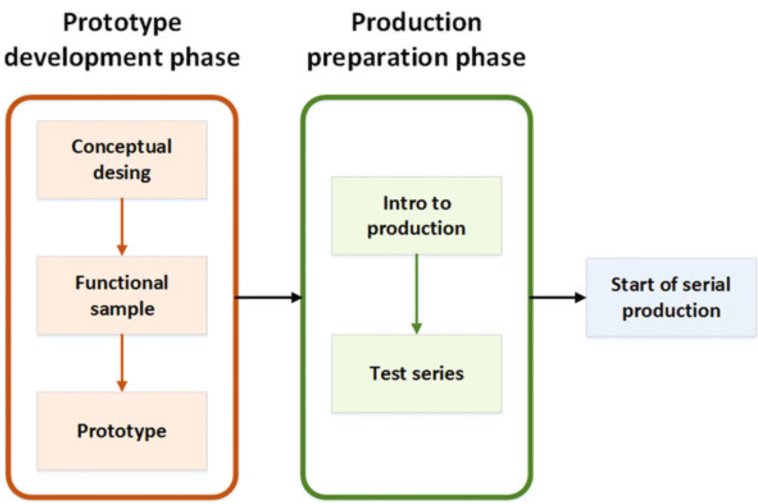


Fig. 1 Phases and activities during firearm development

The prototype represents technical design of a new product, which matches in terms of construction, materials and functionalities with the final product. The prototype is created in order to test all firearm functions, operating features and safety aspects.

Production preparation phase consist of two main activities which aims for the start of serial production. First activity is introduction to production. The goal is to verify the proposed manufacturing processes of a new product and both technology and production equipment that will be used in mass production. In this stage the production of molds and complete tools for serial production is performed. The second activity is the test series where the production runs as in the serial production for some time. The final adjustments are performed.

2.1 Conceptual Design

For analysis and development of new handgun model from the ergonomic point of view the software Tecnomatix Jack and its digital human model was used. This software ranks among the best in its category. Tecnomatix Jack (Tx Jack) contains several anthropometric databases so it is possible to compare firearms models for different populations. Based on these results we can say, what suits and what is appropriate to change. In our ergonomic analysis of a handgun we focused mainly on the suitability of the controls location (trigger, slide stop, magazine catch) and the way of handgun grip. The goal is to ensure maximum comfort during handgun using and also elimination of adverse effects on the user which related to safety use.

Each weapon should be suitable for the widest number of users. Therefore three populations were chosen for analysis [14]. American population was represented by ANSUR database [15], European population by German database [16] and Asian population by Korean database [17]. For each population analyses were carried out for three different sizes of statures thus hands, namely for 5th, 50th and 95th percentile. Furthermore the anthropometry survey of Czech population was performed [18]. Those data were inserted in the ergonomic software TX Jack so DHM representing Czech population was created.

2.2 Functional Sample

After conceptual design a functional sample was created according to the design documentation. Functional sample was made with the technology of 3D printing and was used subsequently for test shooting. The final suitability and user satisfaction was approved by questionnaire of user satisfaction during the test shooting. A total of 18 male subjects participated on test shooting. The mean stature was 177 cm (range, 170–182 cm), mean body weight was 83.5 kg (range, 76–95 kg) and mean age 44.8 years (range, 38–54 years). All subjects had considerable experience and were members of armed forces (police or military). All subjects were healthy and reported no musculoskeletal problems or cardiovascular diseases that could be detrimental to physical performance. The purpose of the questionnaire was explained before test shooting as well as individual questions. The questionnaire consists of 33 questions structured in three groups as follows.

1. Technical parameters with ergonomic influence—evaluated were parameters like trigger (reach, pool, shape), reset length, trigger guard shape and size; grips (frontal side, back side, side grips, materials), magazine length, manipulation with slippery hand; operators reach and pressing (slide stop, magazine release, safety).
2. Technical parameters and utilization—evaluated were parameters like firearm loading and unloading, stiffness of the main spring, cartridge indicator visibility, sight.
3. Handgun favorability—overall handgun design, overall handgun shooting performance.

Rating of individual questions was performed via a 5-point scale similar to school grades: (1) very suitable, (2) suitable, (3) neutral, (4) unsuitable, and (5) very unsuitable. The assistant was asking shooter the predetermined questions related to the areas of assessment and wrote down the results in order to record the score and also the subjective feelings of the shooter. Finally the assistant repeated the areas of assessment and scores to the shooter thus the shooter had the possibility to revise his decision.

The test shootings took place in one day on an indoor shooting range so that no weather conditions would affect the shooter performance. The shooting was performed on the distance of 10 m. There were 3 handguns available for testing—the newly developed functional sample, the predecessor and a direct competitor. Each subject fired 15 shots from each of the three handguns. There were two scenarios. One was focused on aiming and performing a precise shooting, the other one was quickly as possible with drawing from the holster.

3 Results

3.1 Conceptual Design and Digital Human Models Utilization

The DHM were used for design of handgun controls. As stated before, three populations (American, European and Asian) were used. During our comparison of German and Czech hand anthropometry we found out very small differences. There was in most cases (percentiles and dimensions) achieved almost perfect match with maximal difference of up to 3 mm. Greater differences were observed only for females at 95th percentile of the hand length, where Czech arms were shorter by 5 mm. In the case of males, the length of the Czech palms for the 5th percentile was

Fig. 2 An example of digital human model with tested handgun

Fig. 3 Visualization of different trigger positions (*left side wrong trigger position, right side correct trigger position*)

shorter by 4 mm. The largest differences at all were identified for the male hand circumference, where the Czech hands were in the case of 5th percentile greater by 4 mm, in the case of 50th percentile greater by 8 mm and in the case of 95th percentile greater by 9 mm. This diameter, however, could be distorted because of the measured sample, which contained large shares of males working in production, where there is a greater assumption for more muscular hands [18]. From these results we can assume the suitability for Czech as well as German population. Also the analyses of American hand dimensions revealed not very big differences.

After verifying the suitability of anthropometric databases we advanced to analysis of optimal reach limits of the handgun controls. For the individual percentiles of each population the ranges on trigger, slide stop and magazine catch were evaluated as displayed on Fig. 2. The main criterion was the length of index finger and thumb. When evaluating the reach on trigger we also considered carefully the position of index finger on the trigger during shooting. Ideal position of the trigger should be in the middle of the last phalange of index finger as visualized of Fig. 3. Any other position will result in pulling the handgun either to the right or left side during shooting.

With ideal position in mind we have measured the distances for the trigger. The distances were measured from the rear side of the grip plate in other words from the place where base of the thumb came in contact with handgun grip as displayed on Fig. 4. The same procedure was selected when measuring the reach distance for other controls. All distances are summarized in Tables 1 and 2.

Fig. 4 Distances in measurement of handgun controls

Table 1 Reach for trigger

	Minimal distance K (mm)	Average distance K (mm)	Maximal distance K (mm)
Male America + Europe	64.5	69.5	74.5
Male America + Europe + Asia	61.5	67.5	73.5
Male and female America + Europe + Asia	56	64	72

Table 2 Reach for magazine release button and slide stop

	Minimal distance L (mm)	Average distance L (mm)	Maximal distance L (mm)
Male America + Europe	41	46	53
Male America + Europe + Asia	38	44	50
Male and female America + Europe + Asia	33	44	50

Three population groups have been evaluated. The first group consists of American and European males, second group is composed of American, European and Asian males and the last group represents also females of all three populations. The minimal and maximal distances represent 5th and 95th percentiles. Also it must be emphasized that those distances are ideal (from the basic position) which means that there is no need to regrasp the handgun. As can be seen the data dispersion rise with wider population spectrum. Ideal handgun can't be created. Those differences must be adjusted for instance by changeable grip parts.

3.2 Functional Sample and Test Shooting

Males have the majority in armed forces so the first functional sample was created according to the male's dimensions of American and European population. After the test shooting the responses have been analyzed and evaluated. Questions respectively parameters evaluated with worst grade than 3 have been investigated in more detail in order to improve them in future design. The questionnaire results from all three tested handguns are summarized in Table 3. Regarding the trigger and grips evaluation the functional sample ranked as the best before predecessor and direct competitor. The reach on operators was ranked on the direct competitor as the best. This was due to the fact that these questions contained also the amiability regarding the operators pressing. Bad shape and thus the force needed to press the slide stop worsen the rating of the functional sample. In the area of technical parameters and utilization the functional sample had slightly worse rating than the competitor however in the overall handgun evaluation the functional sample was the best. This also shows the average values for the ergonomic evaluation, average

Table 3 Test shooting survey responses

		Predecessor	Direct competitor	Functional sample
Technical parameters with ergonomic influence	Evaluation of trigger	2.47	1.72	1.67
	Evaluation of grips	2.15	2.18	1.38
	Evaluation of operators reach	2.15	1.88	2.11
Technical parameters and utilization	Evaluation of technical performance	2.19	1.75	1.82
Handgun favorability	Overall evaluation of the handgun	2.50	1.92	1.50
Average evaluation	Average of ergonomic evaluation	2.26	1.93	1.72
	Average of ergonomics and utilization	2.24	1.88	1.74
	Total evaluation of the handgun	2.29	1.89	1.70

values of ergonomic evaluation together with technical performance and total evaluation of the handgun.

4 Discussion

Any equipment used by a man should be compatible with physical characteristics. Anthropometry, as a science that's deals with measurements of the size, weight and proportion of the human body, is suitable for this kind of optimization. Mismatches between human anthropometric dimensions and equipment dimensions are known to be a contributing factor in decrease productivity, discomfort, accidents, injuries and cumulative traumas [19, 20]. Hand anthropometry data are essential for handles design, griping options or distances on control buttons. Many aspects must be taken into account such as nationality, gender of the operating person, dominant hand or age group. However no tool is perfect for every user. Anthropometry can still be considered as the key for any attempt to resolve the dilemma of fitting the tool to the human. Designing for humans or human-centered design should improve safety, increase comfort, increase user acceptance, and reduce fatigue and stress.

Research regarding the firearm design focus basically on rifles as a main part of military equipment. Primary attention is given to the effect of rifles weight and length on shooter postural stability and shooting accuracy. Handguns as a backup weapon are being missed out. However regarding the police forces and shooting enthusiastic the handguns are the most popular. This paper focused on the area of handgun operators design and especially the distances. The digital human models and virtual handguns models were used to evaluate new methodology of digital ergonomic design. Recommended distances on handguns operators for three different populations have been stated. For instance for the combined population of American and European males the minimal distance of 64.5 mm, average distance of 69.5 mm and maximal distance of 74.5 mm for the trigger was stated. This is in conformity with US patent 008151504B41 [21] where minimal distance for the trigger is 65 mm, average distance is 70 mm and maximal distance is 75 mm. The suitability of those distances and distances to other handgun operators was confirmed by a functional sample which design was evaluated during test shooting by a questionnaire.

5 Conclusion

The study presented by this paper was the first attempt to utilize digital human models as a tool for human-centered design of a handgun. The results showed that these digital human models can serve for very accurate design of reach distances on handgun controls. Validation was performed by functional sample created with 3D printing method. Although the methodology was validated on handgun there is a wider utilization on rifles and any firearms.

Acknowledgments This paper was created with the subsidy of the internal grant SGS-2015-065-Developing sustainable production system parameters carried out with the support of University of West Bohemia.

References

1. Hancock, P.A., Hendrick, H.W., Hornick, R., Paradis, P.: Human factors issues in firearm design and training. Ergon. Des. **14**, 5–11 (2006)
2. Aalto, H., Pyykkö, I., Ilmarinen, R., Kähkönen, E., Starck, J.: Postural stability in shooters. ORL **52**, 232–238 (1990)
3. Era, P., Konttinen, N., Mehto, P., Saarela, P., Lyytinen, H.: Postural stability and skilled performance—a study on top-level and naive rifle shooters. J. Biomech. **29**, 301–306 (1996)
4. Su, F.C., Wu, W.L., Lee, W.D.: Stance stability in shooters. Chin. J. Med. Biol. Eng. **20**, 187–192 (2000)
5. Mononen, K., Konttinen, N., Viitasalo, J., Era, P.: Relationships between postural balance, rifle stability and shooting accuracy among novice rifle shooters. Scand. J. Med. Sci. Sports **17**, 180–185 (2007)
6. Yuan, ChK, Lee, Y.H.: Effects of rifle weight and handling length on shooting performance. Appl. Ergon. **28**, 121–127 (1997)
7. Kemnitz, C.P., Johnson, R.F., Merullo, D.J., Rice, V.J.: Relation of rifle stock length and weight to military rifle marksmanship performance by men and women. Percept. Mot. Skills **93**, 479–485 (2001)
8. Kuo, ChL, Yuan, ChK, Liu, B.S.: Using human-centered design to improve the assault rifle. Appl. Ergon. **43**, 1002–1007 (2012)
9. Lakie, M.: The influence of muscle tremor on shooting performance. Exp. Physiol. **95**, 441–450 (2010)
10. Tang, W.T., Zhang, W.Y., Huang, C.C., Young, M.S., Hwang, I.S.: Postural tremor and control of the upper limb in air pistol shooters. J. Sports Sci. **26**, 1579–1587 (2008)
11. Hall, M.J.: Measuring felt recoil of sporting arms. Int. J. Impact Eng **35**, 540–548 (2008)
12. Stone, R.T., Moeller, B.F., Mayer, R.R., Rosenquist, B., Ryswyk, D., Eichorn, D.: Biomechanical and performance implications of weapon design: comparison of bullpup and conventional configurations. Hum. Factors **56**, 684–695 (2014)
13. Cornell, M.A., Khasawneh, M.T.: An ergonomic comparison of firearm safety mechanisms. Ergonomics **51**, 1394–1406 (2008)
14. Sekulová, K., Bureš, M., Kurkin, O., Šimon, M.: Ergonomic analysis of a firearm according to the anthropometric dimension. Procedia Eng. **100**, 609–616 (2015)
15. Greiner, T.M.: Hand Anthropometry of U. S. Army Personnel. Massachusetts (1991)
16. DIN 33402-2: Ergonomics—Human body dimensions—Part 2: Values (in German), Ergonomie—Körpermasse des Menchen—Teil 2: Werte. Deutsches Institut für Normung, Berlin (2005)
17. Hart, G.L., Rowland, G.E., Malina, R.: Anthropometric Survey of the Armed Forces of the Republic of Korea. New Jersey (1967)
18. Bureš, M., Görner, T., Šedivá, B.: Hand anthropometry of Czech population. In: International Conference on Industrial Engineering and Engineering Management. IEEE Press, Singapore (2015)
19. Loslever, P., Ranaivosoa, A.: Biomechanical and epidemiological investigation of carpal tunnel syndrome at workplaces with high risk factors. Ergonomics **36**, 537–555 (1993)
20. Keir, P.J., Bach, J.M., Hudes, M., Rempel, D.M.: Guidelines for wrist posture based on carpal tunnel pressure thresholds. Hum. Factors **49**, 88–89 (2007)
21. Alston, C.: Ergonomic firearm grip. US Patent 008151504B41, (2012)

Inspædia: [Almost] Everything About Simplicity, Playfulness and Inspiration

Paulo Maldonado, Fábio Teixeira, José Pinto Duarte, António Câmara, Nuno Correia, Leonor Ferrão, Pablo Ermida and Maria Passos

Abstract The aim of this paper is to disclose the new research developments and the results from the systematization of experience and user interaction with the Inspædia (a new web knowledge "Agora"), to inspire a dynamic, collaborative, and interactive intelligence among the inspædiers. We will explain in detail and describe the design process and discuss the ultimate design interaction concept and development regarding (almost everything about) simplicity and playfulness of the inspædiers' experience to transform relevant information (related > meanfull > useful) in productive knowledge (inspiration > insight > foresight) in a very easy and quick way (usability: learnability; understandability; operability; attractiveness…), with a smile in the face (satisfaction) and a wow in the mind (or in the soul).

Keywords Interaction design · User experience design · Productive thinking

P. Maldonado (✉) · L. Ferrão · P. Ermida · M. Passos
Centro de Investigação em Território, Arquitectura e Design, Rua da Junqueira (CITAD), Universidades Lusíada, Rua da Junqueira, 188-198, 1349-001 Lisboa, Portugal
e-mail: paulomaldonado@inspaedia.com

L. Ferrão
e-mail: lferrao@fa.ulisboa.pt

P. Ermida
e-mail: pabloermida@inspaedia.com

M. Passos
e-mail: mariapassos@inspaedia.com

P. Maldonado · J.P. Duarte · L. Ferrão
Faculdade de Arquitetura, Centro de Investigação em Arquitetura, Urbanismo e Design (CIAUD), Universidade de Lisboa, Rua Sá Nogueira, Pólo Universitário do Alto da Ajuda, 1349-055 Lisboa, Portugal
e-mail: jduarte@fa.ulisboa.pt

M. Soares et al. (eds.), *Advances in Ergonomics Modeling, Usability & Special Populations*, Advances in Intelligent Systems and Computing 486,
DOI 10.1007/978-3-319-41685-4_21

1 *Inspædia* UXD Concept Context

The ambitious objective of offering *inspædiers* a simple, intuitive, meaningful and highly inspirational experience for the processes of design and innovation was present at every stage of the *inspædia* research and development process, from the research for the doctorate degree in Design, including the final document of the thesis entitled *Inovação, design et cetera* (Innovation, design, et cetera), until the present [1–5]. Although we consider that the *inspædia* platform, due to its underlying philosophy, cannot find similar alternatives on the web, it was fundamental to invent a unique and memorable concept that would "takeoff" from the visualization and interaction concepts proposed by other platforms. We wanted to achieve more, with the least possible, a task that we knew to be everything but simple. The complexity inherent to the *inspædia* concept should not, nor could it, transpire to the user experience so that it would not diminish the playfulness of the experience —another objective that we aimed for continuously. We know that the simplicity/playfulness pairing is non-dissociable and, for that reason, it is indispensable to reach a higher level of inspiration—an ultimate objective of *inspædia* (whether for the process or for the results of the posterior application and implementation of inspiration). The complexity on the platform, deliberately "hidden", would serve (only) to feed and enrich (with suggestions) relations and unexpected leaps, the processes of productive thought, amplifying them through the discovery of new meanings and significations and by the possibility to access a new type of perception of the information now made available by *inspædia* to the World that may want to be a part of it [6].

At the origin of the concept of *inspædia* user experience design (UXD) and interaction design (IxD) were, as sources of inspiration, among many other references [7–18], the TEN LAWS and the THREE KEYS of SIMPLICITY [10], the aphorism FORM FOLLOWS FUNCTION [19], the TEN PRINCIPLES FOR

P. Maldonado · F. Teixeira · P. Ermida
Pós-Graduação em Design, Universidade Federal do Rio Grande do Sul,
Avenida Oswaldo Aranha, nº 99, 6º andar - sala 607, Porto Alegre,
RS CEP 90035-190, Brazil
e-mail: fabiogt@ufrgs.br

A. Câmara
Departamento de Ciências e Engenharia do Ambiente, Faculdade
de Ciências e Tecnologia, Universidade
Nova de Lisboa,
Campus de Caparica, 2829-516 Caparica, Portugal
e-mail: antonio.camara@ydreams.com

N. Correia
Nova Lincs—Laboratory for Computer Science and Informatics,
Departamento de Informática, Faculdade de Ciências e Tecnologia, Universidade Nova de
Lisboa, Quinta da Torre, P 2829-516 Caparica, Portugal
e-mail: nmc@fct.unl.pt

GOOD DESIGN [20] and the aphorism FORM FOLLOWS EMOTION [21]. The importance of these references for the *inspædia* concept is, in itself, sufficient to justify the proposed title—«*Inspædia*: [almost] everything about simplicity, playfulness and inspiration» and the article that gives it breadth. Our subtitle will serve, lastly, but not least, to give meaning to the argumentation that we now present and that sustains the essence of the "thing" and the primary "functional" requirement of *Inspædia*, and for which effect we start by calling, chronologically, some of our favorite authors.

In 1896, Louis Sullivan (1846–1924), concerning the article "The Tall Office Building Artistically Considered" announced the law FORM FOLLOWS FUNCTION that found many followers, particularly, among the modernist architects and designers, «Whether it be the sweeping eagle in his flight, or the open apple-blossom, the toiling work-horse, the blithe swan, the branching oak, the winding stream at its base, the drifting clouds, over all the coursing sun, form ever follows function, and this is the law. […] It is the pervading law of all things organic and inorganic, of all things physical and metaphysical, of all things human and all things superhuman, of all true manifestations of the head, of the heart, of the soul, that the life is recognizable in its expression, that form ever follows function. This is the law» [19].

Sullivan's maxima FORM FOLLOWS FUNCTION may have been in the spirit of Dieter Rams (b. 1932) as well as of EVER (meanwhile omitted) and may have been sufficiently inspirational for his reflection on the ethical and conceptual principles that rule (good) design. His TEN PRINCIPLES FOR "GOOD DESIGN" marked (and still mark) the principles that rule the conduct and the professional activity for many designers: "Good design is… innovative; makes a product useful; is aesthetic; makes a product understandable; is unobtrusive; is honest; is long-lasting; is thorough down to the last detail; is environmentally friendly; is as little design as possible" [20]. In sum, the design ethos of Dieter Rams—LESS but MORE that we also pursued and incorporated in the UXD *inspædia*. But Hartmut Esslinger (b.1944) affirms that the aphorism FORM FOLLOWS FUNCTION «was a simplistic and misunderstood reduction of Sullivan's wider description» and amplifies it to FORM FOLLOWS EMOTION, which evokes other notes non-dissociable from form and use—the seduction and the empathy transform the use and the usufruct of a simple experience in a total experience; playfulness [21].

John Maeda (b. 1966) identifies and defends the TEN LAWS and the THREE KEYS of SIMPLICITY. He starts by arguing that «"SIMPLICITY" = SANITY (Technology has made our lives more full, yet at the same time we've become uncomfortably "full")». To this purpose we undertook the TEN LAWS that we have tried to integrate in the concept of the *inspædia* platform, compelled by the mission to reinforce the interaction, the meaning and the experience with a lot of «sense and simplicity»: «REDUCE – the simplest way to achieve simplicity is through thoughtful reduction; […] ORGANIZE—Organization makes a system of many appear fewer; TIME—Savings in time feel like simplicity; […] LEARN—Knowledge makes everything simpler; […] DIFFERENCES—Simplicity and complexity need each other; […] CONTEXT—What lies in the periphery is definitely not peripheral; [...] EMOTION—More emotions are better than less; [...] TRUST—In simplicity we trust; [...] FAILURE—Some things can never be simple; [...] and THE ONE—Simplicity is about subtracting the obvious, and adding the meaningful». Maeda concludes with the following affirmation that complements the TEN LAWS: «THREE KEYS are important technology makers for the future of simplicity: AWAY—More appears like less by simply moving it far, far away; OPEN—Openness simplifies complexity; POWER—Use less, gain more» [10].

In the following section we argue in what way we applied the concept of simplicity to attain playfulness and inspiration.

2 Simplicity, Playfulness and Inspiration

GET INSPIRED (1.2 in Fig. 1) is the provocative and motivational message of action that appears when *inspædiers* (collaborative visual storytellers) access the online platform <www.inspaedia.com> (1.1 in Fig. 1). This if the possible future that we envision and the purpose that moves us (personally) and that moves the community of collaborative intelligence—the *inspædiers*, who, when using the platform, feed it with new contents, new relations between contents, collections of favorite things and navigation trails, contributing to generating, collaboratively, the (individual and collective) inspiration, as well as potentiating new knowledge, by proactively contributing to "BE innovation".

In spite of the access to the platform for non-registered users allowing the exploration of some suggestions of randomized contents (contents with a bigger number of relations and, potentially, more inspirational) (1.3 in Fig. 1), registration is suggested. The new user immediately receives her/his access password via email. Registration allows her/him to access, without limitations, the *inspædia* platform using either of the two modes of visualization and interaction: MAP (1.5 in Fig. 1) e TIME LINE (1.22 in Fig. 1). These two visualization modes, as we will see ahead, through the images that illustrate and support the discourse (Fig. 1), constitute a kind of revolution in perception, because they make possible a new kind of visualization of related contents, of navigation and of interaction. They promote non-linear thought, productive thought (high creativity) and inspiration: MAP, centered exclusively in related images, is organized in concentric circles from the centre to the periphery (by proximity levels that stem from the number of tags common among the contents); TIME LINE, makes apparent the proximity of the contents in a certain time period and organizes and relates the information (in a timeline) through FACTS (relevant occurrences) and ET CETERA (material and immaterial culture, that is, everything that is not facts, but artifacts). The interaction allows the user to jump between the two visualization modes, diversifying and complementing the information, allowing the exploration of the more or less unexpected and obvious relations between the contents (through serendipity or through the text, in a more fine and filtered search—SEARCH).

Fig. 1 *Inspædia* User Experience. *1.1* www.inspaedia.com *1.2* GET INPIRED message *1.3* Clicking for more suggestions *1.4* Mouse through and first level of information *1.5* MAP visualization mode and MENU view *1.6* MENU options: SEARCH, YOU, WE, ABOUT, LOGOUT and MAP, TIME LINE visualization modes buttons, MY TRAIL, ZOOM IN, ZOOM OUT and CENTRE buttons *1.7* Mouse through over a content and first level of information *1.8* Clicking over a content *1.9* After clicking over a content that content becomes the center of the MAP *1.10* Content file complete information *1.11* Interacting with the content file *1.12–1.14* Add a content to a COLLECTION *1.15* Go back the content file *1.16, 1.17* MY TRAIL button, view and interaction *1.18* ZOOM OUT button *1.19* PAN *1.20* CENTRE button *1.21* Centred content *1.22, 1.23* TIME LINE visualization mode *1.24* TIME LINE mouse through and click over a content *1.25* Content file *1.26* Go back by clicking *1.27* Go to MENU *1.28* WE button *1.29–1.31* SEARCH and interacting with COLLECTIONS *1.32* *inspædia* logotype

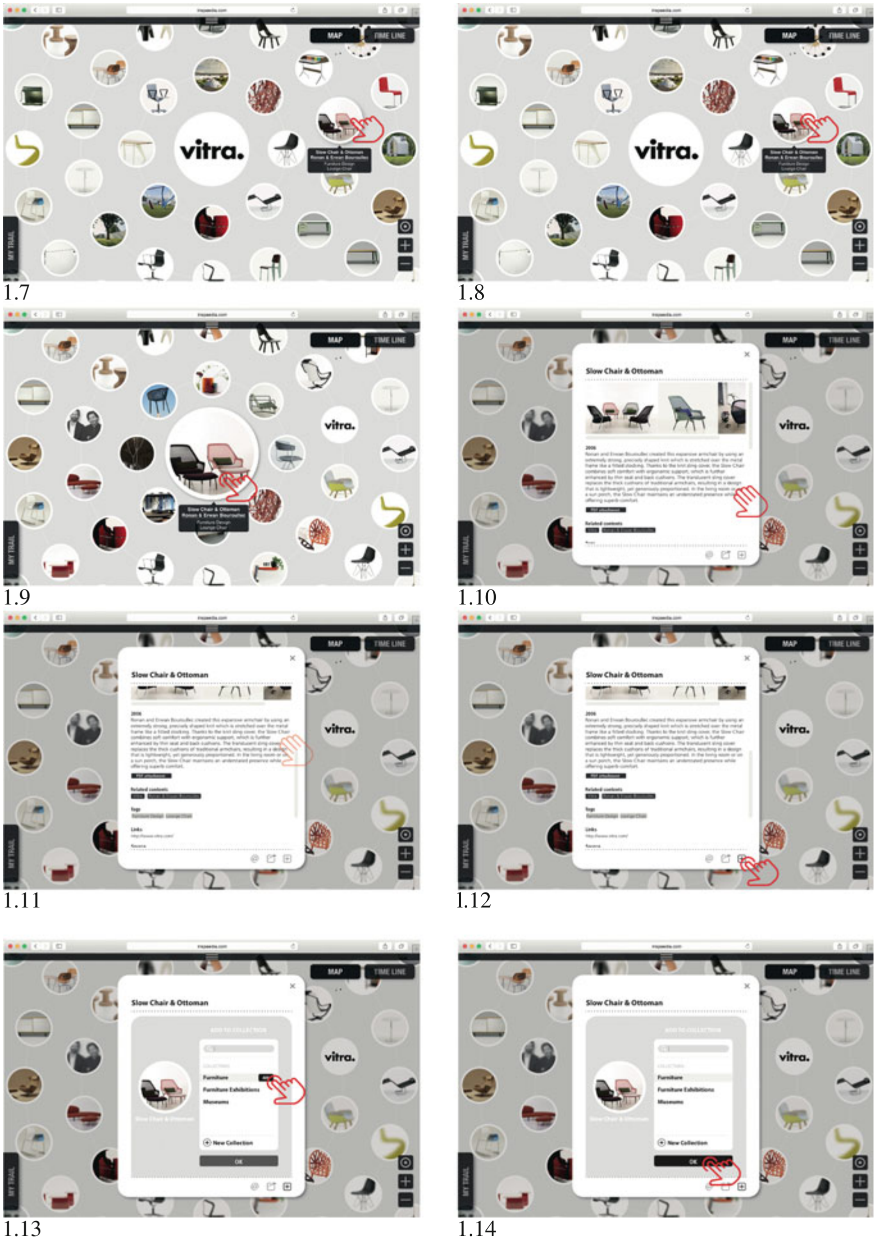
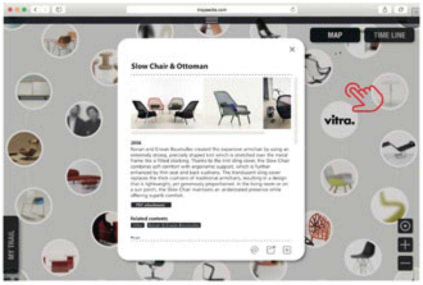
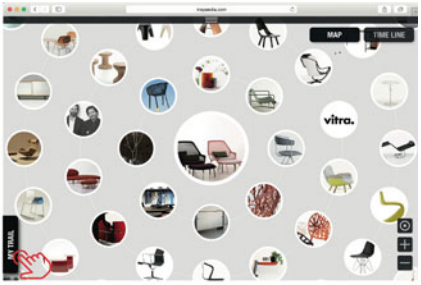


Fig. 1 (continued)

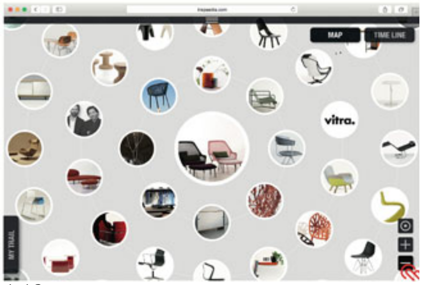


1.15

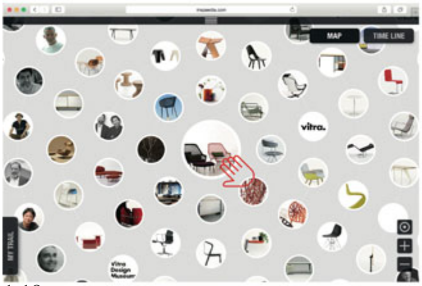


1.16

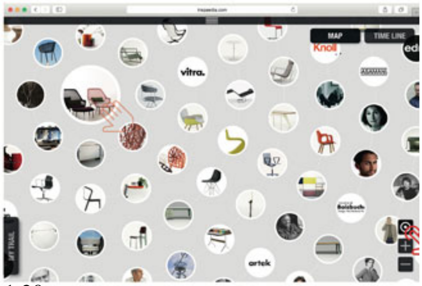
1.17



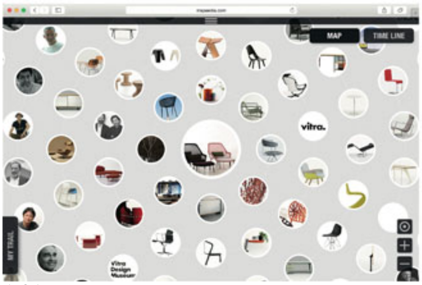
1.18



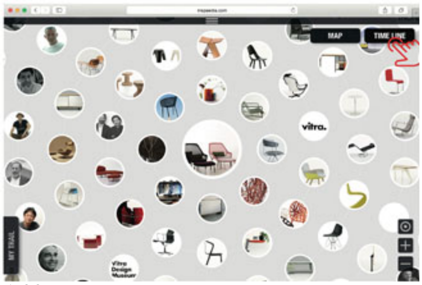
1.19



1.20



1.21



1.22

Fig. 1 (continued)

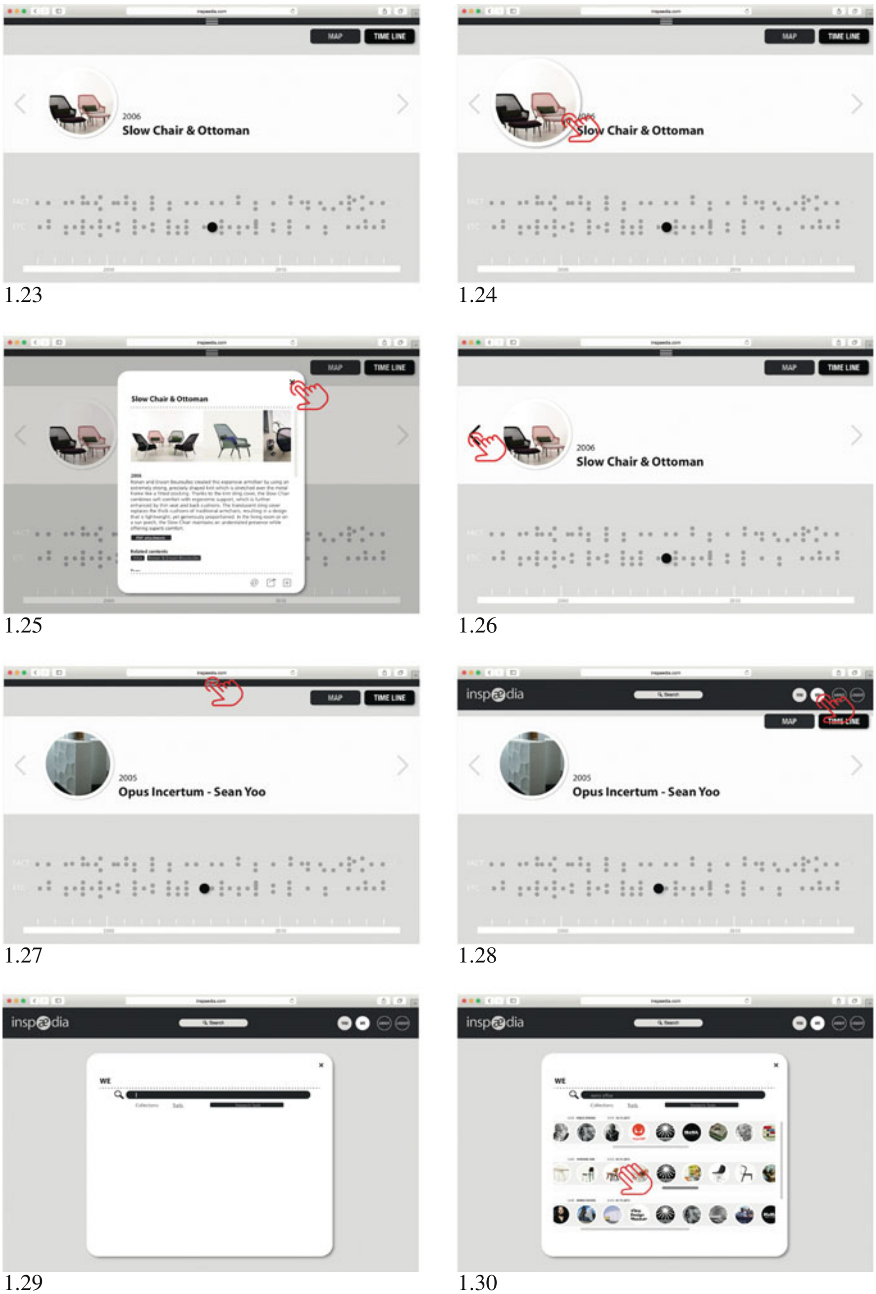
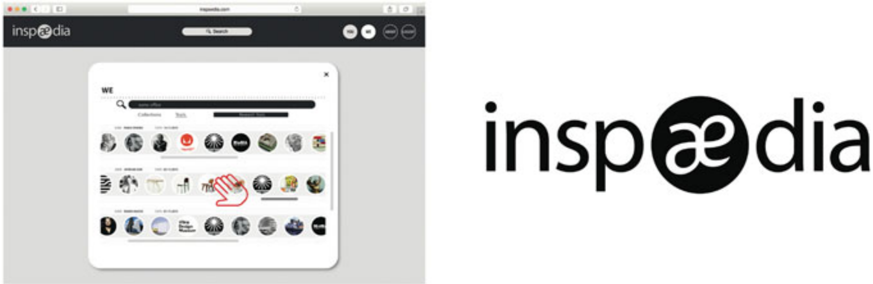


Fig. 1 (continued)



1.31 1.32

Fig. 1 (continued)

When one accesses the *inspædia* platform, the information is organized, on the screen, from the centre to the periphery, the centre being (in its totality) destined to the contents that are related by levels of proximity (MAP) and the periphery destined to operations/actions LOG IN, ABOUT (about *inspædia*), YOU (*inspædier* profile), WE (*inspædiers* collections and trails), SEARCH (through the text), MAP and TIME LINE (for alteration of the mode of visualization and organization of contents), MY TRAIL (i.e. personal navigation history), ZOOM IN, ZOOM OUT (of the contents so as to allow visualizing, simultaneously, a bigger number of related contents) and CENTRE (a certain selected contents) (1.6 in Fig. 1). As we have seen, it is possible to go from the MAP mode of visualization to the TIME LINE mode, bearing in mind that the organization of these two modes of content visualization is distinct. In simplification, the TIME LINE mode of visualization is organized in the two horizontal halves of the screen (1.22 in Fig. 1). In the bottom half of the screen we have the scale of time (pinpointing the years) and the representation, through dots, of all the *inspædia* contents (in this case inscribed and classified as FACTS or ET CETERA) and localized in the corresponding data. Its is possible the interaction, whether with the timescale or with the contents through ZOOM IN, ZOOM OUT and PAN, to move the timescale to a particular year and, thus, to visualize more quickly the contents that are close to it. By doing "mouse through" over a content (dot) an image of that content appears. By clicking on a content one can visualize, in the upper part of the screen, the corresponding image and the brief description of that content. Still in the upper part of the screen it is possible to move forward or to go back from content to content (following a sequential and uninterrupted time line) or to access the content (by clicking the content or the title).

The process of simplification of the visualization of contents, of the relation they establish among themselves and of the navigation and interaction, entailed the definition of the chromatic palette to be used, as neutral as possible so as not to create noise and not overcome what is important (to explore, to visualize and to interact). For the background of the screen we have opted for a simpler and less intrusive solution—the use of gray (15 % black, for being neutral and less tiring to the eyesight, leaving the perception more free to what's essential). For the contents we have opted for their inscription in circles defined by a contouring line, in white. For the buttons and text messages the option was to use the rectangle (with rounded corners), black background (70 % opacity in the buttons) and open white text. We opted for the use of a monochrome palette for all the information that was not contents, so as to minimize the noise. The chromatic (uncontrollable) profusion of the contents was determinant for making this decision. We opted for the differentiation of the geometric figures used for the contents (the circle) and for the buttons (the rectangle with rounded corners). The formal (and chromatic) differentiation is fundamental to activate the perception mechanisms in relation to the identification of, and distinction between, content and secondary action/operation (the interaction reduction for only two types of form simplifies and makes easier the learning and the more intuitive operations). Several tests were made regarding the organization of the contents in concentric circles, with the objective of minimizing the visual and intellectual fatigue brought about by prolonged used. The process of simplification entailed also finding the most adequate geometry, the harmony and visual coherencies and by the definition of the number of contents in each concentric circle, facilitating the perception of the relation of the contents by the proximity among them. It entailed also the dimension of the circles where the contents are inscribed, by the thickness of the content circles' white contour line and by the distance of the content circles among them. We used a white line that unites visually the levels of the contents, so that when one does *pan*, one does not loose the centre. We have tried to find a visual balance between the cluster of contents and the background (interstices) that works, independently of the number of visualized contents simultaneously (in consequence of the zoom in or zoom out) and the dimension of the screen, that may be situated between 7.9″ (iPad Mini 2) and 15″ (MacBook Pro) (most used range of screen dimensions), without setting aside the possibility of attaining 65″ (Smart Kapp IQ). We also had under consideration the dimension of the circle where the content is inscribed so that the perception of the content's image may be easily understood and the content magnification may be more correct when one does "mouse through", so as to not overlap the contiguous contents. With the magnification of the content, a text window (full black rectangle with open text in white) appears simultaneously, corresponding to a first level of information that answers a first level of curiosity about a particular content. Any of each mode of visualization—MAP or TIME LINE—gives the possibility to access the complete information about a particular content and that information (content file) (1.10 in Fig. 1) appears as a result of clicking over the content that aroused the curiosity of the *inspœdier*. The selection of contents, relations between contents and elaboration of the content file is the responsibility of the CONTENT CONSTRUCTORS, and all the *inspœdiers* that gather a competencies profile that is sufficiently distinctive to identify, relate and produce the content description, may be a part of this community, essential for the success of the platform. The content file contains a descriptive text, a list of related contents, a list of tags, links and sources as well as the name of the constructor of that content. By clicking in one of the related contents, or one of the tags, one establishes a new connection and, consequently, one accesses that content in the MAP visualization mode. The navigation and interaction in the content file departs from the same logic of navigation of, and interaction with, the platform, which allows for three possibilities: to send it with added comments, by email, to another *inspædier*, to add that content to a COLLECTION (new or existing) of that *inspædier* (1.13 in Fig. 1) and to share that content on social networks. COLLECTIONS and TRAILS (1.29 in Fig. 1) by the *inspædiers* who may want to share them with the community—an underlying principle of *inspædia*—can be accessed from the YOU and SEARCH buttons (from the SEARCH button it is possible to choose to do an advanced research by using the available filters). From this search, a visual listing of the COLLECTIONS will result if we introduce the name of an *inspædier*, or of a content, or of all TRAILS that include the name of the content on which the search was based. That is the starting point for accessing and exploring the selected COLLECTIONS and TRAILS. We may start at any content of the COLLECTIONS or TRAILS to access the visualization of that content and of all those contents with which it established relations, in any of the modes, MAP or TIME LINE. The existence of MY TRAIL (1.16 in Fig. 1) allows the user to access, at any moment, his or her navigation history in the platform (1.17 in Fig. 1). By navigating in MY TRAIL it is possible, through the navigation and direct interaction with the contents or through the calendar that shows the days in which we have used *inspædia*, to access the previously visualized contents and to erase contents from MY TRAIL. In principle, the MY TRAIL(s), for being inspirational in themselves, can be visualized by any *inspædier*.

The concepts of simplicity and of playfulness were also determining when it was necessary to take decisions regarding typographic sources, icons and the *inspædia* logo. We have used Helvetica type font (Neue Condensed Bold or Helvetica Bold or Regular) for its formal simplicity and good readability. The profusion of icons in the web and the difficulty of identification and memorization bring about enormous confusion and therefore we prefer to opt for very short texts (two words, maximum, to describe an action/operation). In relation to the logotype, we would like to emphasize that the word *inspædia* is a neologism. It is a word composed by ins (piration) + (encyclo)pædia. From this neologism we have drawn a new logotype (1.32 in Fig. 1) with the presupposition that it should fulfill, entirely, the principles of good design previously enunciated. We have sought to explore the graphic characteristic more distinctive of the brand *inspædia* (æ), by transforming it into a memorable symbol inscribed in a circle (chromatically contrasting with the word), that can be used on the web in the most varied scales. We have elected the typographic font Myriad Pro: without serif, it is balanced, harmonious and presents good readability. This font has allowed, also, personalize the "e" because the detail, as minute as it may be, is always perceivable. We folllowed Moogridge advice: «prototype early and often, making each iterative step a little more realistic. At some point you are likely to experience that wonderful "Ah ha!" feeling that comes with a creative leap, but that is only an indication that you have moved forward in the detail of the aspect of the design that you are focusing on right then. You will only know that the design is good when you have tried it out with the people who will use it and found that they are pleased, excited, motivated, and satisfied with the result» [22].

3 By the Way…

Inspædia is the natural consequence and development of the prototype resulting from the research in Design PhD thesis *Innovation, design* et cetera (FA/UTL, 2012). Therefore, it is being developed with the Science Without Borders Program (2013–2016) with a Special Visiting Researcher fellowship grant of CAPES (Brazil), and under the post-doctoral in Design at the Faculty of Architecture, University of Lisbon (FA/UL); CIAUD—Reseach Centre of Architecture, Urbanism and Design (FA/UL); Faculty of Sciences and Technology, Nova University of Lisbon (FCT/UNL); NOVA-LINCS (FCT/UNL) and CITAD—Research Centre for Territory, Architecture and Design (FAA/ULL). The *Inspædia* research project was ranked in first place in Design scientific area and obtained a post-doctoral fellowship by FCT—Foundation for Science and Technology (Portugal). The project has been internationally disseminated at international Design conferences with indexed publications. It was presented and published both at AHFE 2014 (Krakow) and AHFE 2015 (Las Vegas). It was part of the biennial Experimentadesign tangential events in 2013 (EXD'13), 2015 (EXD'15) and was presented, by invitation, at the International Congress DESIGN I-CON (2015). During the last year we prototyped and tested (usability testing) with some *inspædiers* different approaches to achieve users' needs > desires > expectations)—in a challenging way, in order to provide the most powerful and memorable user experience.

The launch of the book "Inspædia: innovation, design et cetera" will take place in 2016. The paper and particularly the viva presentation of the *Inspædia* web platform aspires to get from the scientific community the necessary feedback for the final touches (user experience, interaction design and attractiveness bias) before the online implementation that will happen in September 2016. We hope it will become a viral "social belonging".

Acknowledgments CITAD—Centro de Investigação em Território, Arquitectura e Design, Universidades Lusíada, Lisbon, Portugal; CAPES, Programa Ciência sem Fronteiras, Brazil; PGDesign UFRGS—Universidade Federal do Rio Grande do Sul, Brazil; CIAUD—Centro de Investigação em Arquitectura, Urbanismo e Design, Faculdade de Arquitetura, Universidade de Lisboa, Lisbon, Portugal; This research is financed by CAPES (Fellowship by CAPES/Brazil Ref. A025_2013); This research is also financed by National Funds by FCT—Fundação para a Ciência e a Tecnologia, in the scope of the project (UID/AUR/04026/2013).

References

1. Maldonado, P.: Strategic design: an innovation and design process flowchart. CIPED VI Congresso Internacional de Pesquisa em Design Livro de Resumos. CIPED VI Congresso Internacional de Pesquisa em Design, pp. 292–293. CIAUD, Lisbon (2011)
2. Maldonado, P.: Inovação, Design *et cetera* (Innovation, Design and so on). PhD Thesis, Faculdade de Arquitectura, Universidade Técnica de Lisboa. [S.n.], Lisbon (2012)
3. Maldonado, P., Ferrão, L.: Inspædia: uma Rede de Inteligência Colaborativa Inspiradora (Inspaedia: a Collaborative Intelligence Network). Actas de Diseño – III Congreso Latinoamericano de Enseñanza del Diseño, Año VIII, vol. 15, pp. 193–197. Universidad de Palermo, Buenos Aires (2013)
4. Maldonado, P., Silva, F.M., Gonçalves, F.: Inspædia, inspiring a collaborative intelligence network: designing the user experience. In: 5th International Conference on Applied Human Factors and Ergonomics 20 Volume Set, pp. 463–472: Proceedings of the 5th AHFE Conference 19–23 July (2014)
5. Maldonado, P., Teixeira, F., Silva, F.M., Ferrão, L., Ermida, P., Passos, M.: Inspædia user experience design (UXD), procedia manufacturing. In: 6th International Conference on Applied Human Factors and Ergonomics (AHFE 2015) and the Affiliated Conferences, vol. 3, pp. 6044–6051 (2015)
6. Colborne, G.: Simple and Usable Web, Mobile and Interaction Design. New Riders, Berkeley (2011)
7. Buurman, G.M.: Total Interaction: Theory and Practice of a New Paradigm for the Design Disciplines. Birkhäuser, Basel (2005)
8. Sterling, B.: Shaping Things. MIT Press, Cambridge (2005)
9. Chaoui, C.: Encyplopedia of Human Computer Interaction. Idea Group Reference, Hershey (2006)
10. Maeda, J.: The Laws of Simplicity. MIT Press, Cambridge (2006)
11. Tapscott, D., Williams, A.D.: Wikinomics: How Mass Collaboration Changes Everything. Portfolio, New York (2006)
12. Tidwell, J.: Designing Interfaces. O'Reilly, Sebastopol (2006)
13. Buxton, B.: Sketching User Experiences: Getting the Design Right and the Right Design. Morgan Kaufmann, San Francisco (2007)
14. Anderson, S.: Seductive Interaction Design: Creating Playful, Fun and Effective User Experience. New Riders, Berkeley (2011)
15. Hoekman, R.: Designing the Obvious: A Common Sense Approach to Web and Mobile Application Design. New Riders, Berkeley (2011)
16. Mathis, L.: Designed for Use: Create Usable Interfaces for Applications and the Eeb. The Pragmatic Bookshelf, Raleigh (2011)
17. Weinschenk, S.: 100 Things Every Designer Needs to Know About People. New Riders, Berkeley (2011)
18. Lima, M.: Visual Complexity: Mapping Patterns of Information. Princeton Architectural Press, New York (2013)
19. Sullivan, L.H.: The Tall Office Building Artistically Considered, pp. 403–409. Lippincott's Magazine, Philadelphia (1896)
20. Rams, D.: Ten Principles for Good Design. https://www.vitsoe.com/eu/about/good-design (2016)
21. Esslinger, H.: Design and Emotion. http://www.design-emotion.com/2006/08/15/getting-emotional-with-hartmut-esslinger/ (2006)
22. Moogridge, B.: Designing Interactions, p. 643. MIT Press, Cambridge (2007)

Human-Computer Interaction in Sanitary Inspection Simulation Exercises

Robert Waszkowski, Tadeusz Nowicki and Anna Saniuk

Abstract The paper describes the human-computer interaction principles for each of the teams participating in computer-aided simulation exercises for the State Sanitary Inspection. The exercises relate to activities undertaken during the crisis connected with a large outbreak of food poisoning or food-borne disease. The GUI design and ergonomics for the Training Audience as well as the Exercise Planning Team, the Exercise Control, the Exercise Director and the Evaluation and Analysis Team were considered to immerse the training audience in an as much as realistic environment.

Keywords Human-computer interaction · Systems engineering · Simulation exercises · Foodborne outbreak investigation · Aurea BPM

1 Introduction

The State Sanitary Inspectorate is responsible for the identification, evaluation and management of risks to human health from factors in the environment. Its mission is the prevention and control of communicable diseases, occupational and environmental hazard prevention, surveillance of health and safety as well, as the promotion of public health.

R. Waszkowski (✉) · T. Nowicki
Faculty of Cybernetics, Military University of Technology, Ul. Kaliskiego 2, 00-908 Warsaw, Poland
e-mail: Robert.Waszkowski@wat.edu.pl

T. Nowicki
e-mail: Tadeusz.Nowicki@wat.edu.pl

A. Saniuk
Institute of Computer Science and Production Management, University of Zielona Góra, Licealna 9, 65-417 Zielona Góra, Poland
e-mail: A.Saniuk@iizp.uz.zgora.pl

M. Soares et al. (eds.), *Advances in Ergonomics Modeling, Usability & Special Populations*, Advances in Intelligent Systems and Computing 486,
DOI 10.1007/978-3-319-41685-4_22

Public Health Inspectors are involved in a variety of activities, for example inspecting food facilities, investigating public health nuisances, and implementing disease control. They focus on prevention, consultation, investigation, and education of the community regarding health risks and maintaining a safe environment. In particular, they focus on epidemiological investigations during an outbreak of food-borne disease.

The activities of health inspectors are supported by the computer system, which covers all the workflow and document management during the collection of disease cases, laboratory tests, food-borne disease investigations and outbreak control, inspection and enforcement services, and final report preparation [1].

This study focuses on the human-computer interaction in the sanitary inspection simulation exercises [10] supported by the NESE (the simulation exercises support system) developed by a consortium consisting of the Military Academy of Technology, the Military Institute of Hygiene and Epidemiology, Warsaw Academy of Technology, and Tecna company. The aim of the system implementation is to improve sanitary inspectors' skills in the area of epidemiological investigations relating to a large outbreak of food poisoning or food-borne disease. The research work was carried out as part of project No. PBS1/A7/6/2013.

The aim of the research is to provide appropriate graphical user interfaces as well as communication interfaces between the legacy system and the simulator. The GUI design and ergonomics were considered to be capable of immersing the training audience in an environment as close as possible to the real-world scenario. This means that Public Health Inspectors should not be able to distinguish between a real outbreak and a simulated one.

The results of the GUI design and communication interfaces outlined above are presented in the following chapters describing different teams in simulation exercises.

2 Training Audience

The training audience, as the team undergoing training, should feel no difference between a real and simulated environment [9]. To achieve this all the information that comes from the simulator has to be exactly the same as the information that comes from the real outbreak environment (Figs. 1 and 2).

There are several points to consider because of the fact that some information, e.g. disease case reports or laboratory test reports, is delivered to the State Sanitary Inspectorate in paper form. Even worse is the case with interviews with patients. These are prepared directly in the hospital or the patient's home. In simulation exercises, all situations like this must be handled by the Exercise Control Team supported by the information system [4–6].

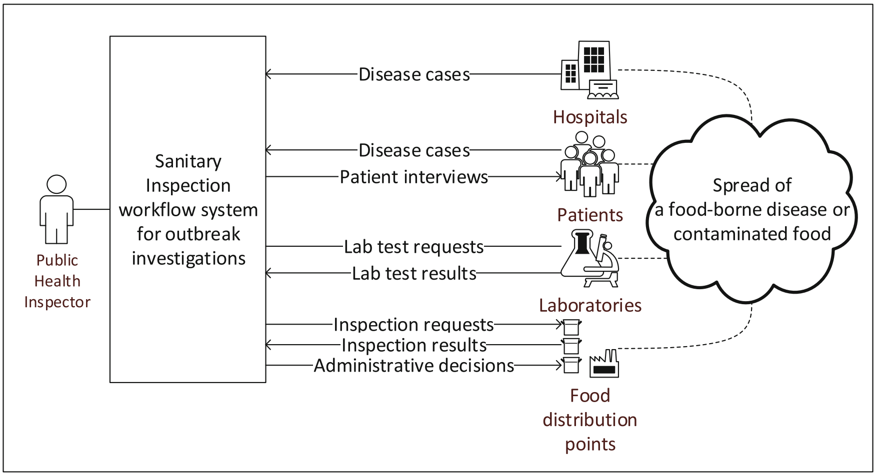


Fig. 1 Training Audience dataflow diagram—real outbreak environment. *Source* own elaboration

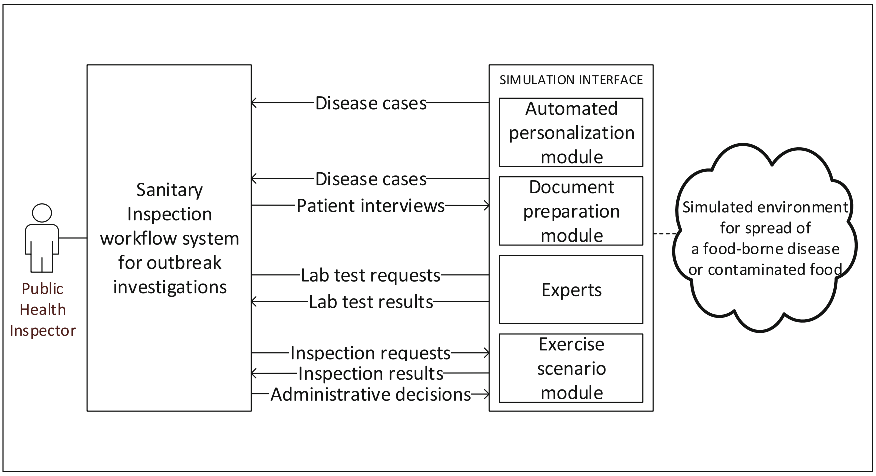


Fig. 2 Training Audience dataflow diagram—simulation exercise environment. *Source* own elaboration

Despite the differences between a real outbreak dataflow and the simulation exercise dataflow, the Exercise Audience must be using exactly the same transactional system [7, 8]. The epidemic investigation repository must be filled with all necessary data, no matter where it comes from. Based on this data, health inspectors

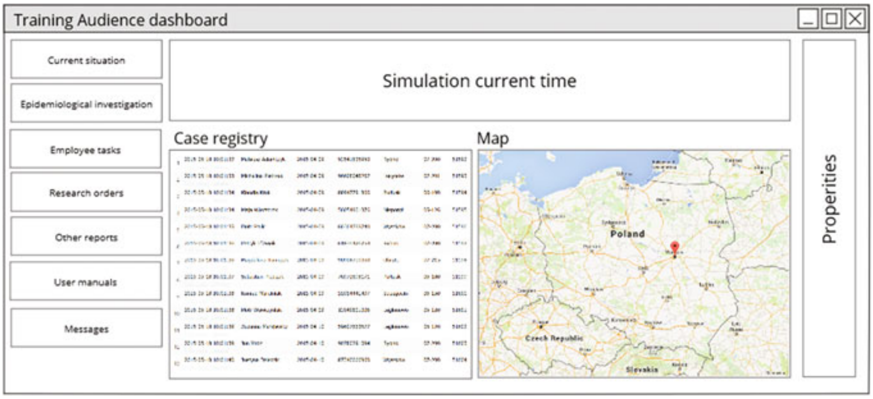


Fig. 3 Training Audience dashboard. *Source* own elaboration

that participate in the exercise make decisions about subsequent steps in the outbreak investigation. They use the dashboard presented in Fig. 3.

3 Exercise Planning Team

The Exercise Planning Team is the core group responsible for the design, development, conduct, and evaluation of an exercise. They determine exercise objectives, create the scenario, develop exercise documentation, and conduct pre-exercise briefing and training sessions [12].

The dashboard for the exercise planning team includes scenario-modeling tools (Fig. 4) and data-preparation tools (Fig. 5).

The scenario-modeling tool is based on the Business Process Management Notation (BPMN). There are two main business processes: the scenario process and the exercise process. During the simulation, the scenario process controls the outbreak situation and reacts to the training audience's responses using the simulators and the Forrester's dynamic models of epidemics [3, 11].

The data preparation tools are very important from the human-computer interaction point of view. This is because the data produced by the simulators and dynamic models are "unpersonified". In order to deliver credible data to the training audience, the information from simulators has to be personified and presented in the form of real documents. To achieve this, the exercise planning team have to prepare an appropriate set of pre-completed documents. Then, during the exercise execution phase, the documents from the previously prepared set are filled out with simulation data [2].

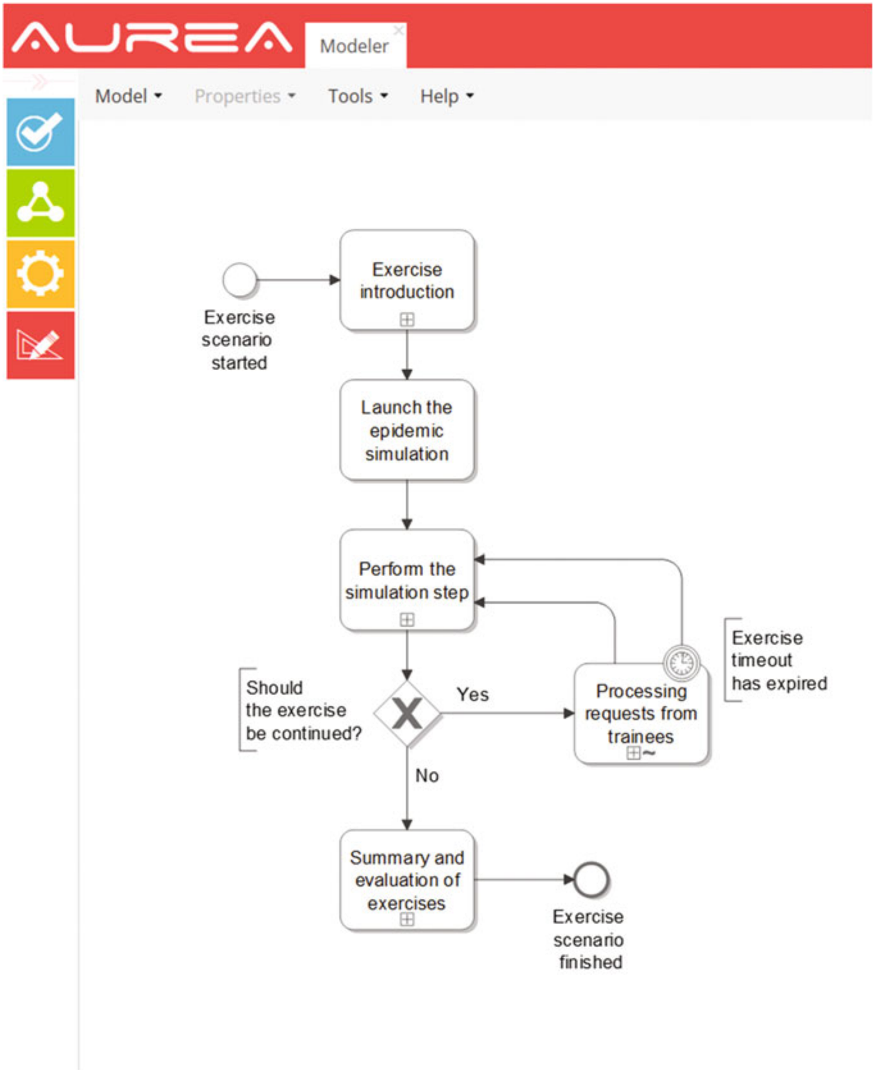


Fig. 4 Scenario modeling tool. *Source* NESE system

4 Exercise Control and Exercise Director

The Exercise Control and Exercise Director dashboards have to be designed in a way that allows full control of the simulation exercise execution, and gives instant access to all parameters resulting from the activities of exercisers (Fig. 6).

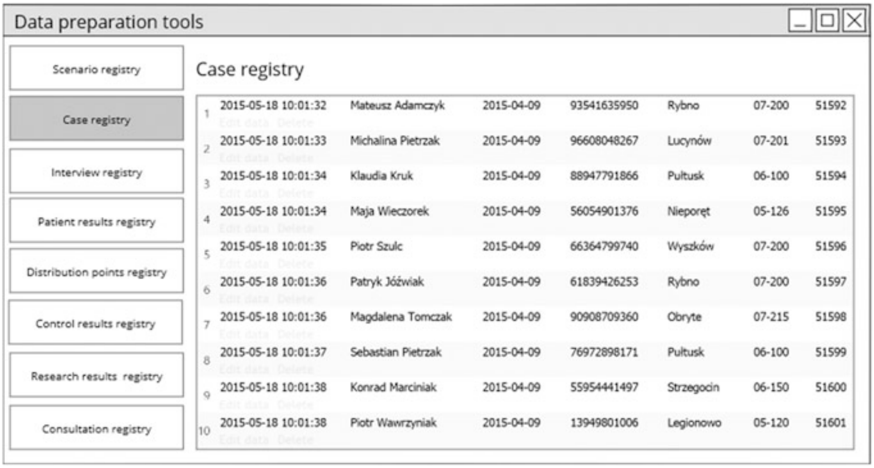


Fig. 5 Data preparation tools. *Source* NESE system

The exercise control team can track the activities of all groups of exercisers and constantly compare their achievements from one integrated place (Fig. 7).

5 Evaluation and Analysis Team

The tasks of the evaluation and analysis team are the review of achieved results and the replay of important situations in the scenario development relating to planning and decision-making activities. Furthermore, "if—then" questions could be analyzed and answered by using the tools provided by the simulation system [2].

Post-exercise analysis involves the use of a variety of techniques to evaluate the data obtained during the exercise. These include Key Performance Indicators (KPIs), reports, charts, and the After Action Review (AAR) technique.

The graphical user interface has to be capable of presenting all necessary indicators, parameters, and execution snapshots in a way that facilitates the review and evaluation of the activities of the individual teams (Fig. 8).

The After Action Review module uses both scenario and execution data derived from simulation exercises, also taking into account the ad hoc operations relating to exercise-audience queries and requests. The AAR module provides access to all the data of the business process, in terms of its execution events, the history of data changes, and timing and cost parameters of tasks. It also guarantees access to aggregated statistical data from other processes, which stem from similar previously conducted simulation exercises. It allows the analyst to define and calculate key

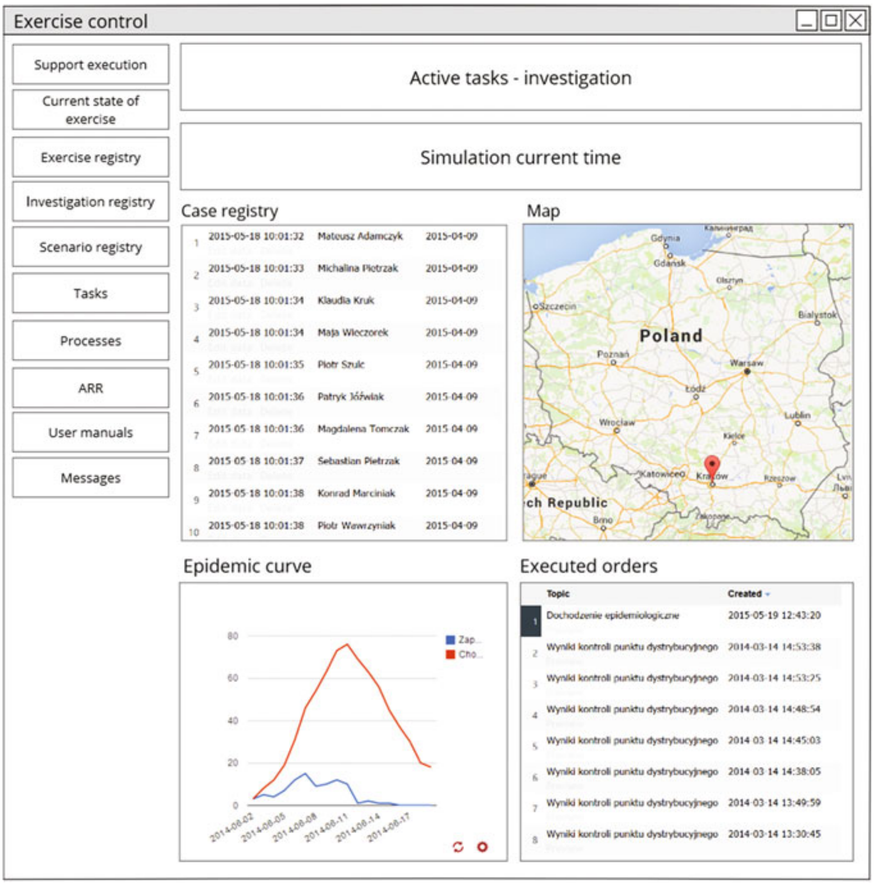


Fig. 6 Exercise control dashboard. *Source* NESE system

performance indicators (KPIs), as well as to define customized reports on the basis of historical process data. It also provides comprehensive data visualization by means of summary tables and charts and gives the opportunity to view the history of simulation exercises on a timeline similar to a "filmstrip". Additionally, it provides synchronization functionality for KPIs presenting the current state of the process (the frame of the filmstrip) and tracks changes in the process data, including the ability to perform "a journey backward in time" and to restart the process from a designated time in the past.

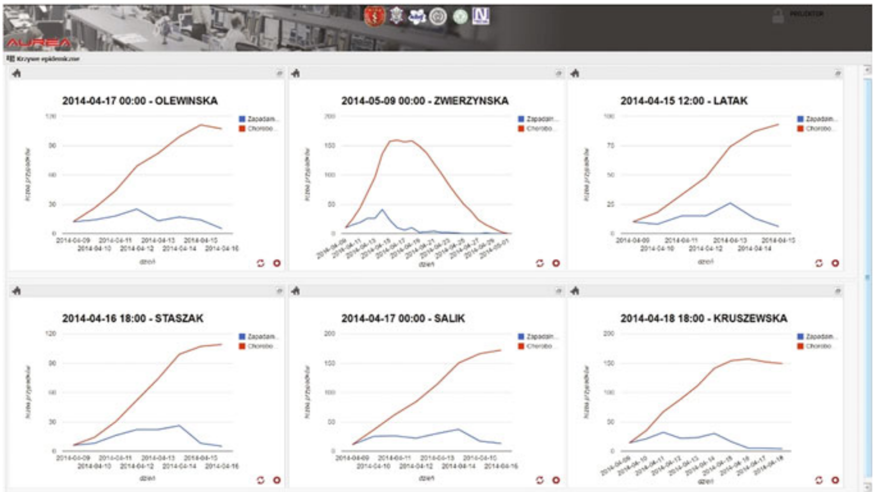


Fig. 7 The preview panel for all individual activities of groups of trainees during simulation exercises. *Source* NESE system

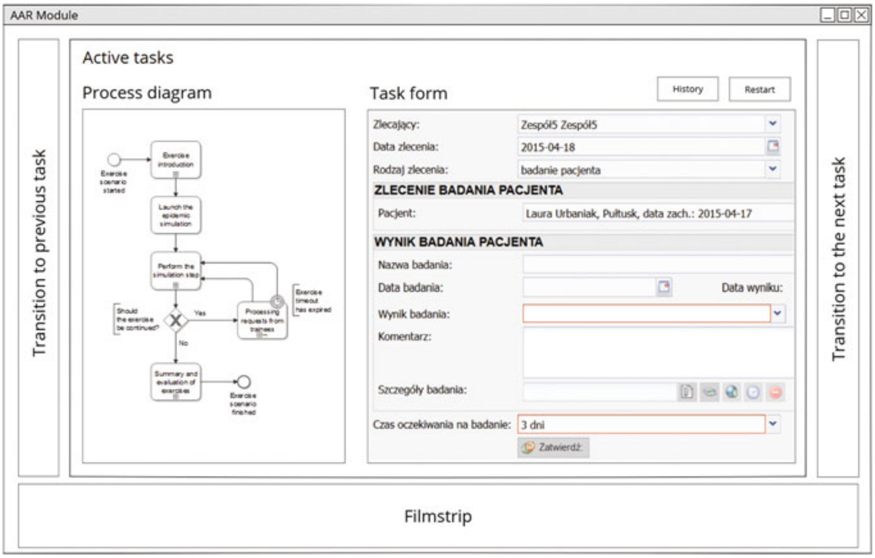


Fig. 8 Graphical user interface of the after action review subsystem. *Source* NESE system

6 Conclusion

Simulation exercises require that appropriate interfaces between the Simulator and the transactional system used in the daily work have to be designed. The data transmitted from the simulator may not differ from the data that the trainees would receive in the case of a real epidemic. For this purpose, it was necessary to construct the subsystem that provides relevant documents to the training audience, based on the data generated in the simulators.

In addition, it was necessary to develop appropriate dashboards for each of the teams participating in the exercise, i.e. the Training Audience, the Exercise Planning Team, the Exercise Control, the Exercise Director, and the Evaluation and Analysis Team. The dashboards are designed in a way that allows completing the tasks executed during the simulation exercises. Simulation of the epidemic has many aspects. Not all of them are capable to be fully automated. Therefore, sometimes it needs the intervention of the subject-matter expert in order to provide relevant data for the exercise audience. It means that the system must be equipped with mechanisms for the preparation of such ad hoc data and delivering them to the exercise audience in the same way as it happens in the real-outbreak workflow.

The exercise audience team cannot feel the difference between the real and the simulated outbreak. Therefore, their desktop is the same as the desktop used during daily work. In fact, this is the same system, supported by the simulation interface module. Consequently the data to be provided by simulators must be submitted directly to the transactional system and presented in the same form as data from a real epidemic.

This paper describes the human-computer interaction principles. The GUI design and communication interfaces were presented for each of the teams participating in computer-aided simulation exercises. This method has been used in the simulation exercises support system (NESE) developed by the consortium as the part of the project mentioned in the Introduction.

References

1. Bertrandt, J., Netczuk, A., Nowicki, T., Tarnawski, T.: Modelowanie, symulacja i analiza procesu rozwoju epidemii chorób przenoszonych drogą pokarmową, Roczniki Kolegium Analiz Ekonomicznych SGH, Zeszyt 29/2013. ISSN 1232–4671
2. Bliźniuk, G.: O kilku warunkach zapewniających interoperacyjność systemów informacyjnych i informatycznych, Biuletyn Instytutu Systemów Informatycznych, nr 3, Warszawa, s. 13–18 (2009)
3. Brailsford, S.C.: Advances and challenges in healthcare simulation modeling: tutorial. In: Proceedings of the Winter Simulation Conference, pp. 1436-1448, Washington, DC, 9–12 Dec 2007
4. Çayırcı, E., Marinčič, D.: Computer Assisted Exercises & Training: A Reference Guide. Joint Warfare Center North Atlantic Treaty Organization Stavanger, Norway. ISBN: 978-0-470-41229-9

5. Cayirci, E., Marincic, D.: Computer Assisted Exercises and Training: A Reference Guide. Wiley, New York (2009)
6. Cayirci, E.: Multi-resolution federations in support of operational and higher level combined/joint computer assisted exercises. In: Proceedings of the 2009 Winter Simulation Conference, Dec 2009
7. Górski, T.: Architectural view model for an integration platform. J. Theor. Appl. Comput. Sci. **6**(1), 25–34 (2012). ISSN 2299-2634
8. IEEE Std 1516 TM-2010.: IEEE Standard for Modeling and Simulation (M&S) High Level Architecture (HLA)—Framework and Rules
9. Jasiulewicz-Kaczmarek, M.: The role of ergonomics in implementation of the social aspect of sustainability, illustrated with the example of maintenance. In: Arezes, P., Baptista, J.S., Barroso, M., Carneiro, P., Lamb, P., Costa, N., Melo, R., Miguel, A.S., Perestrelo, G (eds.) Occupational Safety and Hygiene, pp. 47–52. CRC Press, Taylor & Francis, London (2013). ISBN 978-1-138-00047-6
10. NATO STANAG 4603: Modelling and Simulation Architecture Standards for technical interoperability: High Level Architecture (HLA)
11. Nowicki, T.: The method for solving sanitary inspector's logistic problem. Chapter in monograph. In: Production Management—Contemporary Approaches—Selected Aspects, pp. 23–34. Publishing House of Poznan University of Technology, Poznan (2012). ISBN: 978-83-7775-189-3
12. Schirlitzki, H.J.: Exercises—Planning and Execution in Integration of Modelling and Simulation. NATO Research and Technology Organization (2007). ISBN 978-92-837-0046-3

Quantifying the Effects of Reduced Update Rate on Motor Performance and User Experience

Sung Hun Sim, Bing Wu, Kyle Brady, Andinet Enquobahrie, Ricardo Ortiz and Sreekanth Arikatla

Abstract We report two experiments that investigated the impact of reduced visual updating speed on users' motor performance in a Fitts'-law task. The update rate of visual feedback was set between 10 and 30 Hz. In Experiment 1, the trials were blocked by update rate, allowing participants to get adapted to the reduced visual feedback. In Experiment 2, all trials of different update rates were intermixed and presented in random order. Both experiments found that movement time increased with decreasing update rate. Regression analyses revealed that the Fitts'-law model could be extended to accommodate the findings by including a multiplicative component of frame interval (reciprocal of update rate). The participants' subjective experience reduced rapidly when the update rate was lower than 20 Hz, and the rating data could be modelled using movement time. The results were discussed in the context of implications for developing VR/AR applications.

Keywords Human performance modeling · Update rate · Fitts' law · Feedback delay

S.H. Sim · B. Wu (✉) · K. Brady
Human Systems Engineering Program, Arizona State University, Mesa, AZ 85212, USA
e-mail: Bing.Wu@asu.edu

S.H. Sim
e-mail: Sunghun.Sim@asu.edu

K. Brady
e-mail: kjbrady1@asu.edu

A. Enquobahrie · R. Ortiz · S. Arikatla
Medical Computing Team, Kitware Inc., 101 East Weaver St., Carrboro, NC 27510, USA
e-mail: andinet.enqu@Kitware.com

R. Ortiz
e-mail: ricardo.ortiz@Kitware.com

S. Arikatla
e-mail: sreekanth.arikatla@Kitware.com

M. Soares et al. (eds.), *Advances in Ergonomics Modeling, Usability & Special Populations*, Advances in Intelligent Systems and Computing 486,
DOI 10.1007/978-3-319-41685-4_23

1 Introduction

In many virtual-reality (VR) or augmented-reality (AR) applications such as virtual surgical simulators, the update rate of visualization is often limited by the computational workload required for processing user interactions, calculating mesh deformations, and rendering complex 3D scenes with realistic effects [1, 2]. Previous research has shown that a low update rate of visualization may lead to distorted perception and reduced user experience [3–5]. Low visual update rate may also affect users' motor control. Note also that the control bandwidth of our motor system is quite limited (e.g., the force bandwidth of human muscles is about 2.2 Hz [6] and a position control bandwidth of 5 Hz is sufficient for carrying out most actions [7]). Then does the motor system have a higher tolerance to low update rates than the perceptual system, and how well can users' motor performance be used to predict their subjective experience? In this study, we carried out two experiments using a Fitts's-law target acquisition task to address these questions.

Previous research has extensively examined the impact of reduced visual update rate on users' perceptual experience in immersive VR. The recommended minimum update rate varied from 6 to 30 Hz [8–10], depending the nature of task, viewing conditions, incorporation of other sensory feedback, and user characteristics. On one extreme end, an update rate of 6 Hz was found to be sufficient to give the viewer a sense of presence in virtual environments [8]. A similar value of 7 frames per second was used by Pausch in his implementation of a low-cost VR system in 1990s [9]. On the other end, much higher update rates have been suggested when user stratification and accurate motor performance are highlighted. For example, Mark et al. suggested that update rates of at least 30 and 1000 Hz were needed for visual and haptic feedback, respectively, to create realistic impressions in visual-haptic VRs [10]. While these values are derived mainly from users' subjective experience, research has also examined the impact of reduced update rate on motor behavior in VR. It has been shown that an update rate less than 5 Hz can dramatically increase the task difficulty [11, 12] and 10–15 Hz is usually considered as the minimum update rate for practical use. For example, Watson et al. found that user's grasping performance in VR was compromised at the frame rates of 9 and 13 Hz, but there was no dramatic improvement when the rate was increased from 17 to 25 Hz [12].

The Fitts' law model has been extended to describe the performance deterioration caused by low update rate [12]. In the field of Human Factors Engineering, Fitts' law [13] may be the most successful model used to quantify motor performance and has been widely used to evaluate the effectiveness of different input devices and to compare different design layouts for virtual or physical objects. The law states that the time taken to acquire a visual target with hands, fingers, or pointing devices like mice, joysticks, or touchscreens is a function of the size of the target and the distance to the target. Although there are several variants, the most commonly used version of Fitts' law is

$$Moevment\,Time(MT) = a + b * \log_2\left(\frac{D}{W} + 1\right) = a + b * ID \tag{1}$$

where D is the distance to the target, W is the size of the target, and the logarithmic expression of $\log_2\left(\frac{D}{W} + 1\right)$ is called the Index of Difficulty (*ID*). Although the original Fitts' law does not include the factors like lags or visual update rate, Ware and Balakrishnan [12] revised it to account for their experimental findings. In their Experiment 3, the visual update rate was set to be 0.66–15 Hz and participants' performance was measured in a 3D target acquisition task. The results found that movement time decreased with increasing update rate. In their extended Fitt's-law model, Ware and Balakrishnan considered the reduced updating speed as a cause of system latency

$$System\,Latency = (Device\,Lags + 0.75 * Frame\,Interval) \tag{2}$$

where *Frame Interval* is the reciprocal of the update rate. Accordingly, movement time was described as:

$$MT = a + (b + c * System\,Latency) * ID \tag{3}$$

While system lags and slow updating rate can produce similar effects on motor performance, are they perceived and processed in the same way by the sensorimotor system as implicitly indicated by Eq. (2)? To answer this question, we used a target acquisition task to evaluate the effects of reduced update rate on both motor performance and subjective experience and tried to establish a model to predict users' subjective experience based on their behavioral data. We would compare our results to the findings reported in [14], in which Mackenzie and Ware tested participants in the same mouse-pointing task with different levels of visual latency. Their results revealed a threshold of 75 m s, beyond which latency started to deteriorate performance. Here we experimentally set the update rate to 10–30 Hz (or equivalent increases in latency by 33.3–100 m s) and expected to observe a similar threshold in the effects produced by such low update rates. In addition, two experiments were conducted using an experimental design parallel to [15]. In Experiment 1, the experimental trials were blocked by update rate, allowing participants to eventually get adapted to that update rate over trials. In Experiment 2, all trials were intermixed and different update rates were tested in random order. If the reduced update rate affected the sensorimotor system by increasing the system latency, we expected to observe smaller effects in Experiment 1 because the sensorimotor system would become partially adapted to a constant latency, as we had found in [15].

2 Exp. 1: Target Acquisition Task with Constant Update Rate

In this experiment, participants performed a *2D* target acquisition task with visual feedback at a reduced but constant update rate across all trials. Their motor performance and subjective experience were measured to assess the effects of reduced visual update rate.

2.1 Methods

A Dell Precision T5500 Workstation (Model# T5500, Dell Inc., Round Rock, TX, http://www.dell.com) with an ASUS 27-inch LCD (resolution: 1920 × 1080 @ 120 Hz, Model# VG278HE, ASUSTeK Computer Inc., http://www.asus.com) and a wireless Logitech gaming mouse (Model# G602, Logitech International S.A., Lausanne, Switzerland, http://www.logitech.com) was used. The report rate of the mouse was set to 500 Hz (i.e., one report every 2 m s), and its resolution was reduced to 250 DPI to increase the physical amplitude of mouse movements and hence the task difficulty. All mouse samples were synchronized to the screen refresh rate (120 Hz). The mouse cursor was a red dot of 10 pixels in diameter, which was drew on the LCD with double buffering. Thus the intrinsic delay of the system was no greater than the total delay caused by mouse sampling and screen updating (i.e., 10.3 m s).

The experiment used a Fitts'-law target acquisition task, in which the participant was asked to move a mouse cursor from a home location (the square in Fig. 1a) to a spherical target as quickly and as accurately as possible. The target's size (W) was 32 pixels in diameter, but target distance (D) varied from 80 to 500 pixels, producing a set of target IDs ranging from 1.8 to 4.1. Additional dummy trials were

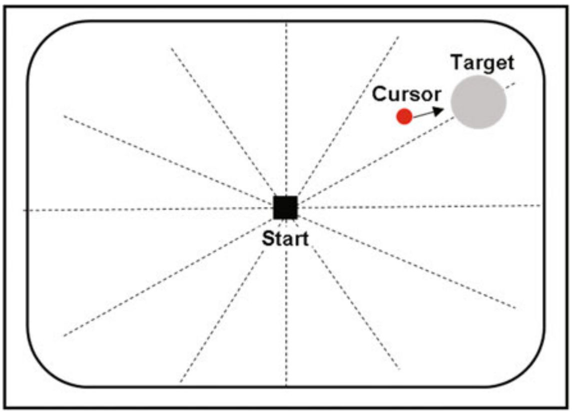


Fig. 1 The target acquisition task and the stimuli

inserted at random between the experimental trials, which had random sizes, distances, and hence the IDs that were quite different from the experimental stimuli.

The independent variable in this experiment was the updating rate of visual feedback. Five levels of updating rate were tested: 10, 15, 20, 24 Hz, or 30 Hz, which were implemented by updating the visualization of the mouse cursor every 12, 8, 6, 5, and 4 screen frames. The experimental trials were blocked by different updating rates: Participants went through five sessions, within which all trials had the same reduced updating rate. Each session contained 80 trials, 56 of which were experimental trials (i.e., 14 repetitions of the four stimuli of different IDs) and another 24 of which were "dummy" trials with random levels of ID. The test order of different latencies was counterbalanced across participants using a Latin square design.

The trajectory of mouse movement was recorded and used to calculate response time and response accuracy. In addition, after each experimental session, participants completed a questionnaire to report their subjective experience about the usability of the mouse. Ratings were collected via three five-point-Likert-scale questions and two nine-point-Likert-scale questions.

Participants were tested individually. At the beginning of each trial, the participant was instructed to click a "start" box located in the center of the screen. Once the box was clicked, a target appeared on the screen after 200 m s with a predetermined distance from the box at one of twelve possible orientations (0°–330° with a step of 30°). The participant was told to move the mouse cursor as quickly and as accurately as possible to the target circle and click it. Once the participant had clicked the mouse, the target circle would disappear and the "start" box would appear again after 1 s, signaling the beginning of the next trial. Typically, a participant finished one trial in less than 5 s and a session in less than 6 min. There was a break of about 5 min for rest after each session. In addition, two practice sessions were run at the beginning of the experiment to familiarize the participant with the task. Practice trials had the same procedure as the experimental trials with the exception that the sizes and IDs of targets were different from the stimuli. The first practice session consisted of twelve 120-Hz-updating-rate trials, whereas the second practice session consisted of twelve 8-Hz-updating-rate trials. The whole experiment took about 1 h.

Twenty undergraduate and graduate students (18 males and 2 females, aged 18–45 years) from Arizona State University participated in this experiment with informed consent. To eliminate the possible effects of handedness, all participants were right-handed by self-report and performed the experiment using their right hand. They were naïve to the purposes of this study.

2.2 Results

All participants showed high accuracy (>95 %) in the task, and thus the error rate was not statistically analyzed. Our analyses focused on movement times and subjective ratings. Movement times (MTs) were measured as the time between the onset of the stimulus and the completion of the mouse movement. Figure 2a plots the mean MTs,

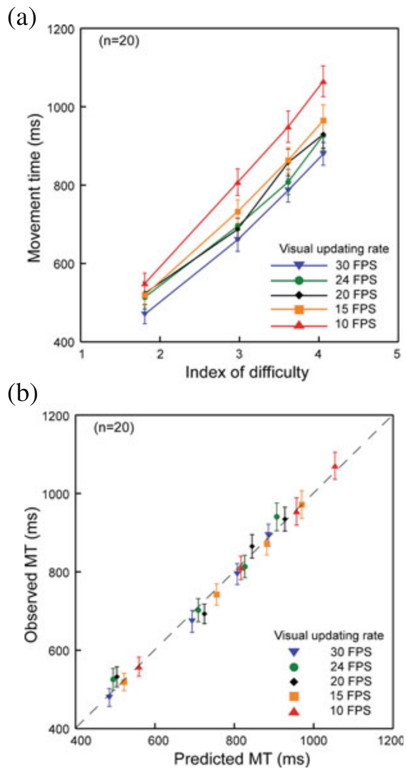


Fig. 2 Results of Experiment 1. **a** The mean movement time (MT) as functions of Index of Difficulty (ID) and visual update rate. **b** The observed MTs versus the predictions from Eq. (4). The error bars stand for ±1 standard error

averaged across all participants, as functions of IDs and Update-rates. Clearly, both variables produced significant effects on MT: The average MT increased linearly with ID at all update rates, and the slower the visual updating rate, the faster the MT increased with ID. A two-way 4 × 5 repeated measures ANOVA found significant main effects of both ID (F(3, 57) = 308.370, p < 0.001, partial η = 0.942) and Update-Rate (F(4, 76) = 35.706, p < 0.001, partial η^2 = 0.653). There was also a significant interaction between ID and Update-Rate (F(12, 228) = 3.451, p < 0.001, partial η^2 = 0. 154).

MTs increased gradually as the update rate decreased. From 30 to 10 Hz, the visual latency (i.e., the *Frame Interval* in [12]) was increased by 33.3–100 m s. No sudden changes in MT were observed that might indicate a threshold as suggested in [14]. Instead, regression analyses showed that all MTs could be described very well (Fig. 2b, $r^2 = 0.99, p < 0.001$) with one parameter in the following modified Fitts' law model:

$$MT = 162.92 + (157.58 + 0.62 * Frame\ Interval) * ID \quad (4)$$

where *Frame Interval* is the reciprocal of update rate [12].

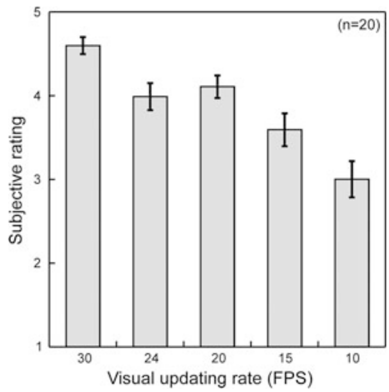


Fig. 3 The mean subjective rating obtained at different update rates. The error bars stand for ±1 standard error

As shown in Fig. 3, the participants' subjective experience also worsened with decreasing update rate. A one-way repeated measures ANOVA revealed significant effects of Update-Rate ($F(4, 76) = 17.871$, $p < 0.001$, partial $\eta^2 = 0.485$). However, unlike what we had observed in MTs in Fig. 2a, a perceptual threshold was found here: The average rating changed from >4.1 for update rates no less than 20 Hz, to 3.5 for an update rate of 15 Hz, and then to 3.1 when the update rate was reduced to 10 Hz. Since the ratings obtained using the questionnaire was a type of mean opinion score (MOS) and a value below 3.6 is often termed "unacceptable", thus a visual updating rate of 20 Hz seemed to be the minimal for achieving user satisfaction.

Then how well could users' subjective experience be related to their motor performance? A regression analysis was performed to assess the relationship among mean error rate, mean movement length, mean movement time, and mean subjective rating. Movement time was found to be the best predictor of subjective ratings ($p < 0.01$) and it could account for a majority of the variation observed in ratings ($r^2 = 0.95$). As shown below, the value of the coefficient was negative (−0.011), indicating that participants might mainly rely on the perceived movement time to make the usability rating: Longer movement durations were usually associated with increased difficulty of use and hence lower ratings as the update rate decreased and the visual latency increased.

$$Rating\,score = 12.59 - 0.011 * MT \quad (5)$$

3 Exp. 2: Target Acquisition Task with Variable Update Rate

In contrast to Experiment 1, all experimental trials were intermixed and different visual update rates tested in random order in this experiment. The purpose was to create an unpredictable testing environment to prevent participants from getting adapted to visual latencies caused by reduced updating rates. By comparing the results from this and the previous experiment, we could assess the possible effects of adaptation on users' sensorimotor performance.

3.1 Methods

The experimental setup and procedure were identical to Experiment 1. The experimental design was also identical to Experiment 1, with the only exception that the experimental trials of difference visual updating rates were intermixed and presented in random order. All trials were grouped into 7 sessions, each of which contained a total of 55 trials, 40 experimental trials and 15 "dummy" trials.

Another group of twenty undergraduate students (16 males and 4 females, aged 18–29 years) participated in this experiment with consent. All were right-handed by self-report and performed the experiment using their right hand. They were naïve to the purposes of this study.

3.2 Results

As in the previous experiment, our analyses focused on movement time (MT). Figure 4a plots the mean MTs as functions of IDs and Update-rates. Same as Experiment 1, a two-way 4×5 repeated measures ANOVA was conducted, which found significant main effects of ID ($F(3, 57) = 374.480$, $p < 0.001$, partial $\eta^2 = 0.952$) and Update-Rate ($F(4, 76) = 58.313$, $p < 0.001$, partial $\eta^2 = 0.754$), and also a significant (ID $\times$ Update-Rate) interaction ($F(12, 228) = 2.636$, $p = 0.003$, partial $\eta^2 = 0.\ 122$). Similarly, regression analyses showed that all MTs could be described very well ($r^2 = 0.99, p < 0.001$) using the following modified Fitts' law model:

$$MT = 147.24 + (174.11 + 0.59 * Frame\,Interval) * ID \tag{6}$$

Next, between-experiments comparisons were made to assess the effects of sensorimotor adaptation to visual latencies. A $2 \times 4 \times 5$ mixed-measures ANOVA found no statistically significant differences (*ps* > 0.23), although the MTs were slightly longer in Experiment 2 (intermixed trials of different update rates) than in Experiment 1 (trials blocked by update rate). This was consistent with the findings reported in [16, 17] that variations in update rate would affect motor performance unless the standard deviation of *Frame Interval* exceeded a high threshold of 82 m s. The update rates used in this study yielded short *Frame Intervals*. Thus although the update rate varied from trial to trial in Experiment 2, the variations in *Frame Interval* might still be too small to produce any significant effects.

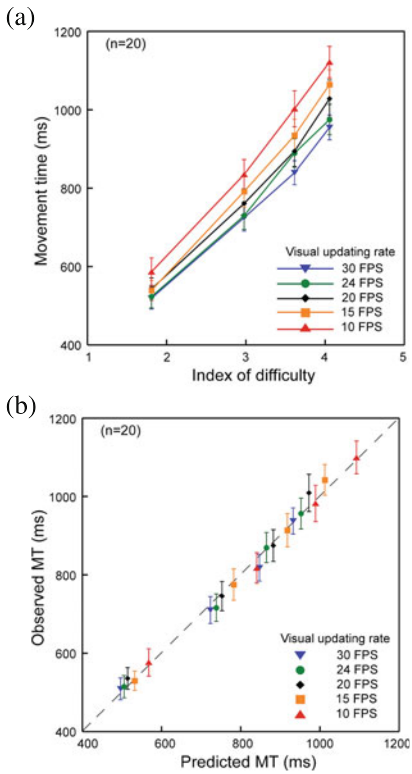


Fig. 4 Results of Experiment 2. **a** The mean movement time (MT) as functions of Index of Difficulty (ID) and visual update rate. **b** The observed MTs versus the predictions from Eq. (6). The error bars stand for ±1 standard error

4 Discussion

The findings from this study clearly showed that the updating speed of visual feedback, when reduced to a certain level, could significantly impact users' subjective experience and their motor performance even in a simple mouse-pointing task. As compared the perceptual system, our sensorimotor system seems to be more sensitive to slow visual updating: As the update rate decreased, the movement time gradually increased while the users' subjective experience was little influenced until the rate was reduced below 20 Hz. Although a 2D pointing task was tested here, we expect that the findings can be generalized and extended to a wide range of motor tasks. There is no doubt that the tasks that require more feedback for guidance and corrections will be affected more by reduced visual updating speed. In many VR/AR applications, particularly in medical applications, users heavily rely on visual feedback to perform delicate and complex operations. The updating speed of visual feedback should be more important for performing such tasks. Based on our findings, we recommend a minimum update rate of 20 Hz to achieve sufficient user satisfaction, and the higher the update rate, the better.

Another issue to be considered in the design of VR/AR applications is the variability in visual updating speed. The computational workload can vary significantly when the scene switches or when the user initiates or terminates an action. Adaptive algorithms have been developed to distribute the workload as evenly as possible across time. Still, the update rate cannot be constant. In [16, 17], Watson et al. systematically examined the impact of variable update rate on the performance of visually guided motor responses. They found that variations in update rate could affect user performance, but the variation had to be quite large to produce observable effects. Here we obtained similar results. The experimental trials were blocked by update rate in Experiment 1 to allow participants to get adapted to a fixed update rate, while the rate changed from trial to trial in Experiment 2 to introduce large variations. Still, no significant differences were found when comparing the experimental results. Clearly, our sensorimotor system is not so sensitive to the variations in visual feedback speed. Thus it will be preferable for engineers to devote more effort to improving the mean update rate, rather than keeping the rate constant.

5 Conclusion

We have shown that the updating speed of visual feedback, when reduced to a certain level, could significantly affect users' subjective experience and their motor behavior. A number of practical recommendations can be derived from our findings. To design user-friendly VR/AR applications, our results suggest that an update rate of >20 Hz may be needed. Although it will be desirable to keep the update rate constant, we find that it will be more important to make the mean update rate as high as possible since variations in the update rate have only weak effects on user performance. These recommendations may be applied to the design of VR/AR/teleoperative systems.

Acknowledgments The work was supported in part by NIH grants 5R00EB008710 & 9R44OD018334.

References

1. Arikatla, V., Ortiz, R., Thompson, D., Adams, D., Enquobahrie, A., De, S.: A hybrid approach to simulate tissue behavior during surgical simulation. In: 4th International Conference on Computational and Mathematical Biomedical Engineering—CMBE2015 (2015)
2. Sheridan, T.B.: Telerobotics, Automation, and Human Supervisory Control. MIT Press, Cambridge (1992)
3. Apteker, R., Fisher, J., Kisimov, V., Neishlos, H.: Video acceptability and frame rate. IEEE Multimedia **2**(3), 32–40 (1995)
4. Steinmetz, R.: Human perception of jitter and media synchronization. IEEE J. Sel. Areas Commun. **14**(1), 61–72 (1996)

5. Steinicke, F., Bruder, G.A.: Self-experimentation report about long-term use of fully-immersive technology. In: Proceedings of the 2nd ACM Symposium on Spatial User Interaction, pp. 66–69 (2014)
6. Aaron, S.L., Stein, R.B.: Comparison of an EMG-controlled prosthesis and the normal human biceps brachii muscle. Am. J. Phys. Med. **55**, 1–14 (1976)
7. Brooks, T.: Telerobotic response requirements. In: Proceedings of the International Conference on Systems, Man and Cybernetics, pp. 113–120 (1990)
8. Airey, J., Rohlf, J., Frederick, P.: Towards image realism with interactive update rates in complex virtual building environments. In: SI3D '90: Proceedings of the 1990 Symposium on Interactive 3D Graphics, pp. 41–50 (1990)
9. Pausch, R.: Virtual reality on five dollars a day. In: Proceedings of the SIGCHI Conference on Human Factors in Computing Systems, pp. 265–269 (1991)
10. Mark, W.R., Randolph, S.C., Finch, M., Verth, J.: Adding force feedback to graphics system: issues and solutions. In: Proceedings of the 23rd Conference on Computer Graphics, pp. 447–452 (1996)
11. Bryson, S.: Effects of lag and frame rate on various tracking tasks. In: Proceedings of SPIE, Stereoscopic Displays Appl. IV, vol. 1925, pp. 155–166 (1993)
12. Ware, C., Balakrishnan, R.: Reaching for objects in VR displays: Lag and frame rate. ACM Trans. Comput. Hum. Interact. **1**(4), 331–357 (1994)
13. Fitts, P.M.: The information capacity of the human motor system in controlling the amplitude of movement. J. Exp. Psychol. **47**(6), 381–391 (1954)
14. MacKenzie, S., Ware, C.: Lag as a determinant of human performance in interactive systems. In: Proceedings of the ACM Conference on Human Factors in Computing Systems—INTERCHI, pp. 488–493 (1993)
15. Brady, K.: Taking Fitts' slow: the effects of delayed visual feedback on human motor performance and user experience. M.S. thesis, Arizona State Univ., Tempe, AZ (2015)
16. Watson, B., Spaulding, V., Walker, N., Ribarsky, W.: Evaluation of the effects of frame rate variation on VR task performance. In: Proceedings of IEEE Virtual Reality Annual Symposium, pp. 38–44 (1997)
17. Watson, B., Walker, N., Ribarsky, W., Spaulding, V.: Effects of variation in system responsiveness on user performance in virtual environments. Hum. Factors **40**(3), 403–414 (1998)

Modeling Reduced User Experience Caused by Visual Latency

Kyle Brady, Bing Wu, Sung Hun Sim, Andinet Enquobahrie, Ricardo Ortiz and Sreekanth Arikatla

Abstract Two experiments were conducted to investigate the influence of delayed visual feedback on users' motor performance and subject experience. In a Fitt's-law target acquisition task, participants moved a cursor from a home location to a spherical target with delayed visual feedback. The experimental trials were blocked by latency (Experiment 1) to allow participants to get adapted to a constant delay or tested in random order (Experiment 2). Both experiments found significant impact of delay on motor performance, and the larger the Index of Difficulty of movement, the greater the performance detriment. A modified Fitts'-law model described the results very well with an additional multiplicative component of latency. Participants' ratings of subjective experience with different latencies could be well-predicted from their motor performance. Between-experiments comparisons further revealed the effects of sensorimotor adaptation to constant delays. The results provide guidance to the design of VR/AR/tele-operative applications.

Keywords Human performance modeling · Feedback delay · Latency · Fitts' law · Pointing

K. Brady · B. Wu (✉) · S.H. Sim
Arizona State University, Mesa, AZ 85212, USA
e-mail: Bing.Wu@asu.edu

K. Brady
e-mail: kjbrady1@asu.edu

S.H. Sim
e-mail: Sunghun.Sim@asu.edu

A. Enquobahrie · R. Ortiz · S. Arikatla
Medical Computing Team, Kitware Inc., 101 East Weaver St., Carrboro, NC 27510, USA
e-mail: andinet.enqu@Kitware.com

R. Ortiz
e-mail: ricardo.ortiz@Kitware.com

S. Arikatla
e-mail: Sunghun.Sim@Kitware.com

M. Soares et al. (eds.), *Advances in Ergonomics Modeling, Usability & Special Populations*, Advances in Intelligent Systems and Computing 486,
DOI 10.1007/978-3-319-41685-4_24

1 Introduction

We rely on vision not only for perception but also for action: We use vision to guide and regulate almost all motor activities ranged from simple actions like reaching for a coffee mug, to fine movements like writing and drawing, and to very delicate operations like surgery. Naturally, continuous and immediate visual feedback is sent to the motor system for correcting and fine-tuning movements. Nevertheless, such sensorimotor control is often altered in many computer-based or internet-based activities owing to delayed visual feedback. For example, the commercially available touchscreens typically take 50–200 ms to update the display [1]. In many virtual-reality (VR), augmented-reality (AR), and tele-operation applications, a delay in visual feedback is inevitable due to the latencies caused by sampling, transmitting, processing, and rendering the image signals. So the questions are, how much is the maximum delay that can be tolerated by the perceptual and motor systems, and how well can the sensorimotor control mechanisms adapt to visual delays? To address these questions, two experiments were conducted to evaluate the impact of visual latency on participants' motor performance in a 2D target acquisition task and their subjective experience.

Mixed results have been reported on the influence of visual latency on motor performance. Mackenzie and Ware [2] tested participants in a mouse-pointing task with different levels of visual latency. Their results revealed a threshold of 75 m s, beyond which latency started to deteriorate performance. On the other hand, high tolerance of visual delays is often found in many industrial and medical applications. For example, the first trans-Atlantic telerobotic surgery was successfully performed with a mean lag of 155 m s between the surgeon's movements and the video image [3]. Kim et al. [4] examined the influence of delayed visual feedback on teleoperation and found that the task completion time eventually increased with delay, and when the delay was longer than 400 m s, the operators usually switched to a move-and-wait strategy. Day, Holt and Russell [5] examined the effects of even longer delays (2–6 s) and explained their findings in terms of cognitive mechanisms that may be used to predict and compensate some effects of visual delays. Clearly, visual delays may influence our motor control mechanisms at different levels, depending on task difficulty, the type of motor operation, and the amount of delay.

Fitts' law [6] has been modified to describe the performance deterioration caused by delayed visual feedback [2, 7]. In the field of Human Factors Engineering, Fitts' law may be the most successful model used to quantify motor performance and has been widely used to evaluate the effectiveness of different input devices and to compare different design layouts for virtual or physical objects. The law states that the time taken to acquire a visual target with hands, fingers, or pointing devices like mice, joysticks, or touchscreens is a function of the size of the target and the distance to the target. Although there are several variants, the most commonly used version of Fitts' law is

$$Moevment\,Time(MT) = a + b * \log_2\left(\frac{D}{W} + 1\right) = a + b * ID \quad (1)$$

where D is the distance to the target, W is the size of the target, and the logarithmic expression of $\log_2\left(\frac{D}{W} + 1\right)$ is called the Index of Difficulty (ID). As the original Fitts' law does not include the factors like visual latency, Mackenzie and Ware [2] modified it to account for their experimental findings. In their experiments, participants moved a mouse cursor from a starting position to a target with a visual latency ranged from 25 to 225 m s. Their results showed that the effects of visual latency were observable only when it was longer than 75 ms. Moreover, the effects varied with task difficulty: the harder the task, the greater the increase in the movement time. Accordingly, the movement time could be described as:

$$MT = a + b * ID(for\,all\,latencies \leq 75\text{ m s}) \quad (2)$$

$$MT = a + (b + c * Latency) * ID(for\,all\,latencies > 75\text{ m s}) \quad (3)$$

This modified Fitt's law model has been used by many researchers to inform the design of virtual environments where visual latencies usually exist. In addition, it has been extended to account for movements in 3D space [7].

The presence of lag in visual feedback may also alter our perception and subjective experience. Our previous research and other work have shown that the visual system is sensitive enough to reliably detect delays of 40–60 m s [8–10]. When virtual soft objects was felt with delayed visual feedback in a visual-haptic VR, even a sub-threshold delay could cause an overestimation of object stiffness, and such overestimation increased in a linear fashion with delay [8]. In immersive VRs, visual delay can have such profound effects on subjective experience that users gave low ratings of their VR experience and even rejected VRs because of "simulator sickness" caused by long latencies [11]. With this in mind, then how can subjective user experience be modeled and predicted with the presence of visual feedback delays?

In this study, we used a target acquisition task as in [2] to evaluate the effects of visual latency on both motor performance and subjective experience and tried to establish a model to predict users' subjective experience based on their behavioral data. Another question to be examined here was how well people could adapt to a constant latency. Two experiments were conducted. In Experiment 1, the experimental trials were blocked by latency, allowing participants to eventually get adapted to a constant delay over trials. In Experiment 2, all trials of different visual latencies were intermixed and tested in random order to create an unpredictable testing environment. By comparing the results from the two experiments, we could assess not only the effects of latency but also the effects of adaptation on users' motor performance and their subjective experience.

2 Exp. 1: Target Acquisition Task with Constant Visual Latencies

This experiment was designed to investigate how a constant visual latency could influence users' performance of 2D target acquisition task and also their subjective experience.

2.1 Methods

Participants. 10 undergraduate and graduate students (8 males and 2 females, aged 18–59 years) from Arizona State University participated with informed consent. To eliminate the possible effects of handedness, all participants were right-handed by self-report and performed the experiment using their right hand. They were naïve to the purposes of this study.

Experimental setup. As shown in Fig. 1a, the participant sat in front of a 27-in. LCD (resolution: 1920 × 1080 @ 120 Hz, Model# VG278HE, ASUSTeK Computer Inc., http://www.asus.com) and performed the pointing task using a wireless Logitech gaming mouse (Model# G602, Logitech International S.A., Lausanne, Switzerland, http://www.logitech.com). The report rate of the mouse was set to be 500 Hz (i.e., one report every 2 m s), and its resolution was reduced to 250 DPI to increase the physical amplitude of mouse movements and hence the task difficulty. A multi-threaded program was implemented in C++ and run on a Dell Precision T5500 Workstation (Model# T5500, Dell Inc., Round Rock, TX, http://www.dell.com) for controlling the presentation of the experimental stimuli, recording the trajectory of mouse movements, and calculating response times. The mouse cursor was visualized as a red circular marker with a 10-pixels diameter, which was drew on the LCD with double buffering at a refresh rate of 120 Hz. Note that the report rate of the mouse was 500 Hz. Thus the intrinsic delay of the system was no greater than 10.3 m s. In addition, the sampling and recording of the mouse trajectory was synchronized with the screen refresh rate. An additional visual delay, when needed, was then inserted between mouse movement and cursor motion by showing the cursor at an old location.

Design & procedure. The experiment used a Fitts'-law target acquisition task, in which the participant was asked to move a mouse cursor from a home location (the square in Fig. 1b) to a spherical target as quickly and as accurately as possible. The target's size (W) was 32 pixels in diameter, and four pre-defined target distance (D) were selected to establish a set of target IDs ranging from 1.8 to 4.1. In addition, dummy stimuli were inserted at random between the stimuli, which had random sizes, distances, and hence the IDs that were quite different from the experimental stimuli.

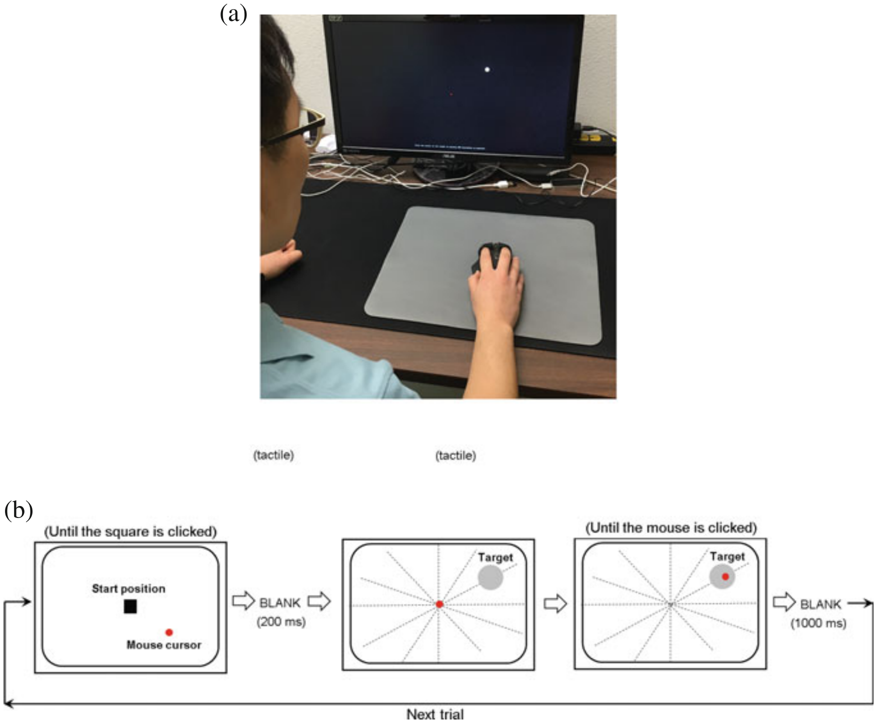


Fig. 1 **a** Experiment setup. **b** The sequence of events on each trial in the experiment task

The independent variable in this experiment was the additional latency in visual feedback, which had five levels ranged from 0 to 16 frames with a step of 4 frames (i.e., 0–133 m s with a step of 33 m s). The experimental trials were blocked by different latency levels: Participants went through five sessions with each session having a constant level of latency for all trials. Each session contained a total of 80 trials, 56 of which were experimental trials (i.e., 14 repetitions of the four stimuli of different IDs) and another 24 of which were "dummy" trials with random levels of ID. The test order of different latencies was counterbalanced across participants using a Latin square design.

The dependent variables were response time and accuracy, which were used to assess the participant's performance at each level of latency. In addition, after having completed all trials at one latency level, participants were asked to complete a five-question questionnaire to report their subjective experience about the usability of the mouse at the latency level tested. Ratings were collected via three five-point Likert scales and two nine-point Likert scales.

Participants were tested individually. As shown in Fig. 1b, each trial began with the presentation of a "start" box in the center of the screen. The participant was instructed to click the box to start the trial. Once the box was clicked, a target appeared on the screen after 200 ms with a predetermined distance from the box at one of twelve possible orientations (0°–330° with a step of 30°). The participant was instructed to move the mouse cursor as quickly and as accurately as possible to the target circle and click it. Once the participant had clicked the mouse, the target circle would disappear and the "start" box would appear again after 1 s, signaling the beginning of the next trial. Typically, a participant finished one trial in less than 5 s and a session in less than 6 min. There was a break of about 5 min for rest between the sessions. In addition, two practice sessions were run at the beginning of the experiment to familiarize the participant with the task. Practice trials had the same procedure as the experimental trials with the exception that the sizes and IDs of targets were different from the stimuli. The first practice session consisted of twelve 0-m s-latency trials, whereas the second practice session consisted of twelve 200-m s-latency trials. The whole experiment took about 1 h.

2.2 Results

Only correct responses were analyzed, in which the participant successfully clicked inside of the target circle. Since all participants showed very high accuracy rates (> 95 %) in the task, the error rate was not statistically tested. Instead, our analyses focused on movement time and subjective ratings.

Movement times (MTs) were recorded from the onset of the stimulus to the completion of the mouse movement. Figure 2a plots the mean MTs, averaged across all participants, as functions of IDs and latencies. Clearly, the results largely replicated the findings reported in [2]: MT increased almost linearly with ID at all latency levels, and the longer the visual latency, the faster the MT increased. A two-way 4 × 5 repeated measures ANOVA found significant main effects of both ID ($F(3, 27) = 113.008$, $p < 0.001$, partial $\eta^2 = 0.926$) and Latency ($F(4, 36) = 29.494$, $p < 0.001$, partial $\eta^2 = 0.766$). Additionally, there was a significant interaction between ID and Latency ($F(12, 108) = 42.789$, $p < 0.001$, partial $\eta^2 = 0.826$).

Different from what reported in [2], we did not observe a latency threshold in our results. Although a latency of 33 m s was below the perceptual threshold reported in [8–10], MTs were found to be significantly influenced: As compared to the zero-latency condition, MTs were significantly larger in the 33-m s-latency condition ($F(1, 9) = 6.282$, $p = 0.03$, partial $\eta^2 = 0.386$). Regression analyses further showed that all MTs could be described very well ($r^2 = 0.98, p < 0.001$) using the following modified Fitts' law model:

$$MT = 44.75 + (170.31 + 0.65 * Latency) * ID \tag{4}$$

As shown in Fig. 2b, the participants' subjective experience also reduced gradually with latency. A one-way repeated measures ANOVA revealed significant effects of Latency ($F(4, 36) = 18.435$, $p < 0.001$, partial $\eta^2 = 0.672$). However,

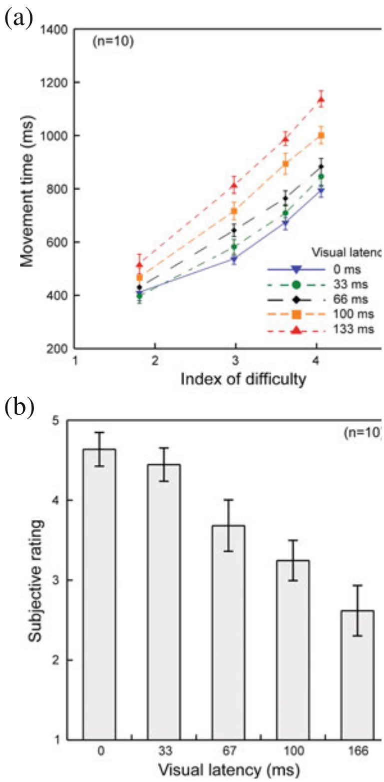


Fig. 2 **a** The mean movement time (MT) as functions of Index of Difficulty (ID) and visual latency. **b** The mean subjective rating obtained at different latency levels. The error bars stand for ±1 standard error

unlike what we had observed in MTs, a perceptual threshold of ~66 m s was found here: The pairwise comparison between the 0-m s-latency and 33-m s-latency conditions found no significant difference ($t(9) = 1.035$, $p = 0.33$, Cohen's $d = 0.69$), but both ratings were found to be significantly higher than that obtained in the 66-m s-latency condition ($t(9) > 2.766$, $p = 0.02$, Cohen's $d = 1.85$). That is, the participant's subject experience with the task started to deteriorate until the visual latency was about 66 m s, although their behavioral data already showed weak but significant effects in MTs.

3 Exp. 2: Target Acquisition Task with Variable Visual Latencies

In contrast to Experiment 1, all trials of different visual latencies were intermixed and tested in random order in this experiment. The purpose was to create an unpredictable testing environment to prevent participants from getting adapted to visual latencies. By comparing the results obtained from this and the previous experiment, we could assess the possible effects of adaptation on users' motor performance.

3.1 Methods

Participants. Another group of ten undergraduate students (9 males and 1 females, aged 19–24 years) participated in this experiment with consent. All were right-handed by self-report and performed the experiment using their right hand. They were naïve to the purposes of this study.

Experimental setup, design & procedure. The experimental setup and procedure were identical to Experiment 1. The experimental design was also identical to Experiment 1, with the only exception that the experimental trials of difference latencies were intermixed and presented in random order, rather than being blocked by latency. All trials were grouped into 7 sessions, each of which contained a total of 55 trials, 40 experimental trials and 15 "dummy" trials.

3.2 Results

As in the previous experiment, our analyses focused on movement time (MT). Figure 3 plots the mean MTs as functions of both IDs and latencies. Same as Experiment 1, the effects of ID and Latency were evident. A two-way 4 × 5 repeated measures ANOVA revealed significant main effects of ID ($F(3, 27) = 280.064$, $p < 0.001$, partial $\eta^2 = 0.969$) and Latency ($F(4, 36) = 20.544$, $p < 0.001$, partial $\eta^2 = 0.695$). The (ID × Latency) interaction was also found to be significant ($F(12, 108) = 80.647$, $p < 0.001$, partial $\eta^2 = 0.900$). Similarly, regression analyses showed that all MTs could be described well ($r^2 = 0.97, p < 0.001$) using the following modified Fitts' law model:

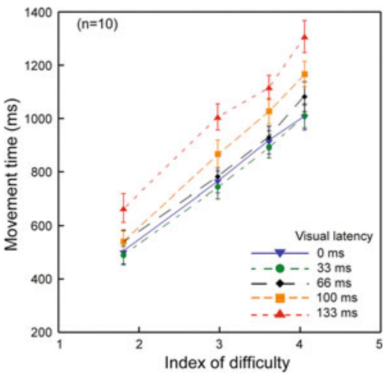


Fig. 3 The mean MT as functions of ID and visual latency. The error bars stand for ±1 standard error

$$MT = 93.38 + (211.82 + 0.55 * Latency) * ID \tag{5}$$

Next, we made between-experiments comparisons to evaluate the effects of adaptation to constant latencies. A 2 × 4 × 5 mixed-measures ANOVA found significant differences between blocked-latency (Experiment 1) and mixed-latency (Experiment 2) conditions ($F(1,\ 18) = 5.189$, $p < 0.05$, partial $\eta^2 = 0.224$). The differences can be seen in Figs. 2a and 3: The MTs shown in Fig. 3 were clearly longer than those shown in Fig. 2a in all latency conditions. A quantitative comparison of two models, Eq. (4) versus Eq. (5), showed that the constant (i.e., *a* in the modified Fitts'-law model) was larger (93.38 vs. 44.75 m s) in Eq. (5) than in Eq. (4). This suggests that when a visual latency is constant, the sensorimotor system may eventually get adapted to the delay, compensate some latency effects, and shorten the response time.

4 Discussion

The findings from the two experiments clearly showed that the delayed visual feedback could significantly impact a user' motor performance in a 2D target acquisition task and also his or her subjective experience. As the visual latency increased, the movement time increased while the subjective rating reduced. Then how well could the users' subjective experience be related to their motor performance? A regression analysis was performed to assess the relationship among mean error rate, mean movement length, mean movement time, and mean subjective rating across all latency levels. Movement time was found to be the best predictor of subjective ratings ($p < 0.01$) and it could account for a majority of the variation observed in ratings ($r^2 = 0.96$). As shown below, the value of the coefficient was negative (−0.008), indicating that participants might mainly rely on the perceived movement time to make the usability rating: Longer movement durations were usually associated with increased difficulty of use and hence lower ratings as the visual latency increased.

$$Rating\ score = 9.154 - 0.008 * MT \tag{6}$$

Although the above models were derived from the data collected in a 2D target acquisition task using a mouse, we expect that the findings and models can be generalized and extended to real-world applications that involve delayed visual feedback and a wide range of motor tasks and input devices. For example, in many VR/AR applications, whereas considerable effort has been devoted to improving visualization, a delay in visual feedback is still unavoidable because a certain amount of time is always needed to retrieve the data from sensors, update the virtual models, render the graphical effects with sufficient realism, and then transmit the images to the displays like head-mount displays (HMDs). Moreover, users often

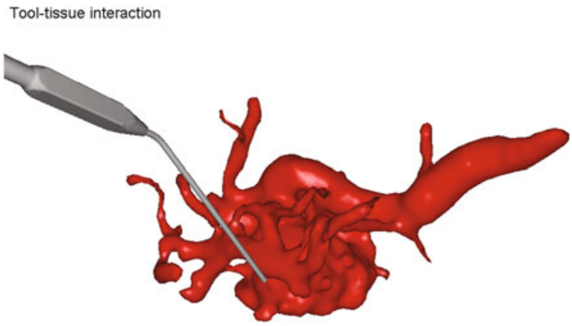


Fig. 4 The neural surgical simulator

perform 3D motor tasks in immersive VR/AR environments, for example, gesture-based gaming using the Microsoft's Kinect sensor. As such applications are becoming more and more popular, it will be important to quantitatively predict how visual latency will influence users' performance and experience. We expect that a similar pattern may be observed regarding the impact of visual latency on 3D motor tasks as well as user experience.

The comparison between the two experiments showed that our sensorimotor system can quickly get adapted to a constant visual delay, at least partially. When the experimental trials were blocked by latency, participants performed the task with faster speed and shorter movement time. Note that no participants had used such a slow-response (latency ranged from 33 to 133 m s) mouse in their daily activities. Still, they quickly adapted to the device and improved their performance over a short testing time of <6 min. Based on these results, we suggest that a visual delay, if unavoidable, should be kept constant to facilitate the sensorimotor adaption.

While the longest latency examined in this study was 133 m s, in many real-world situations, tasks may have to be performed with much longer visual delays, for example, as in the trans-continent telerobotic surgeries [3]. Previous research has shown that it is possible for users to cope with long delays [3–5] and some cognitive mechanisms may be involved to compensate the perceptual effects of such delays. To further study such cognitive mechanisms, we will extend the current work to more complicate motor operations using a surgical simulator shown in Fig. 4.

5 Conclusion

We have shown that delayed visual feedback can significantly reduce users' motor performance and subjective experience. A number of practical recommendations can be derived from the experimental results. First, since the results found significant decreases in user experience when the delay increased from 33 to 66 m s, it is recommended to keep the delay shorter than 66 m s to ensure user satisfaction. Second, a constant visual delay is preferable for facilitating the sensorimotor adaption. The recommendations may be applied to the design of VR/AR/teleoperative systems where delayed visual feedback is always a nuisance.

Acknowledgments The work was supported in part by NIH grants 5R00EB008710 & 9R44OD018334.

References

1. Ng, A., Lepinski, J., Wigdor, D., Sanders, S. Dietz., P.: Designing for low-latency direct-touch input. In: Proceedings of the 25th Annual ACM Symposium on User Interface Software and Technology (UIST ’12). ACM, New York, NY, USA, pp. 453–464 (2012)
2. MacKenzie, S., Ware, C.: Lag as a determinant of human performance in interactive systems. In: Proceedings of the ACM Conference on Human Factors in Computing Systems—INTERCHI, pp. 488–493 (1993)
3. Marescaux, J., Leroy, J., Rubino, F., Vix, M., Simone, M., Mutter, D.: Transcontinental robot assisted remote telesurgery: feasibility and potential applications. Ann. Surg. **235**, 487–492 (2002)
4. Kim, T., Zimmerman, P.M., Wade, M.J., Weiss, C.A.: The effect of delayed visual feedback on telerobotic surgery. Surg. Endosc. **19**(5), 683–686 (2005)
5. Day, P.N., Holt, P.O., Russell, G.T.: Modeling the effects of delayed visual feedback in real-time operator control loops: a cognitive perspective. In: Alty, J.L. (ed.) Proceedings of the XVIII European Annual Conference on Human Decision Making and Manual Control, pp. 70–79. Group D Publications Ltd., Loughborough (1999)
6. Fitts, P.M.: The information capacity of the human motor system in controlling the amplitude of movement. J. Exp. Psychol. **47**(6), 381–391 (1954)
7. Ware, C., Balakrishnan, R,: Target acquisition in fish tank VR: the effects of lag and frame rate. In: Davis, W.A., Joe, B. (eds.) Proceedings of Graphics Interface ‘94, pp. 1–7 (1994)
8. Wu, B., Sim, S., Enquobahrie, A., Ortiz, R.: Effects of visual latency on visual-haptic experience of stiffness. In: Proceedings of the 7th International Workshop on Quality of Multimedia Experience (QoMEX 2015), IEEE, Paper#84 (2015)
9. Vogels, I.M.L.C.: Detection of temporal delays in visual-haptic interfaces. Hum. Factors **46** (1), 118–134 (2004)
10. Shi, Z., Hirche, S., Schneider, W., Muller, H.J.: Influence of visuomotor action on visual-haptic simultaneous perception: a psychophysical study. In: Proceedings of 16th Symposium on Haptic Interfaces for Virtual Environments and Teleoperator Systems, pp. 65–70 (2008)
11. Steinicke, F., Bruder, G.A.: Self-experimentation report about long-term use of fully-immersive technology. In: Proceedings of the 2nd ACM Symposium on Spatial User Interaction, pp. 66–69 (2014)

How Do Needs and Preferences of a User, Match the Settings of the Interfaces They Use

Eleni Chalkia, Evangelos Bekiaris and Ignacio Lopez Madrid

Abstract ICT have been moving rapidly into people's lives nowadays. Even if living without access to ICT would be a barrier in the past, today access to ICT is required for most education, employment, and commerce, and is increasingly required for travel, health, safety, daily living and participation in most of our society. In this paper we present how the needs and preferences of the users are reflected and covered by the ICT interfaces they use.

Keywords Accessibility · Human-systems integration · Interface · Users with disabilities

1 Introduction

ICT have been moving rapidly into people's lives nowadays. Surprisingly, there are lots of people nowadays, who even if they know how to use and interact with ICT, they don't. The main reason behind this is because they cannot, due to the lack of having the appropriate accessible settings enabled. Thus, the available settings do not match the needs and preferences of the user and this leads, in most of the cases, to non-usable interfaces for them and in the worst cases not accessible at all.

Even if living without access to ICT would be a small and maybe meaningless barrier in the past, today access to ICT is required for most of the daily life tasks

E. Chalkia (✉) · E. Bekiaris
Hellenic Institute of Transport Center for Research and Technology Hellas,
57100 Thessaloniki, Greece
e-mail: hchalkia@certh.gr

E. Bekiaris
e-mail: abek@certh.gr

I.L. Madrid
ILUNION Consultoría, Accessibility, Studies and R&D,
C/Albacete, 3, 28027 Madrid, Spain
e-mail: NMadrid@consultoria.ilunion.com

M. Soares et al. (eds.), *Advances in Ergonomics Modeling, Usability & Special Populations*, Advances in Intelligent Systems and Computing 486,
DOI 10.1007/978-3-319-41685-4_25

like education, employment, and commerce, and is increasingly required for travel, health, safety, daily living and participation in most of our society, for ALL. Especially for people with specific needs and preferences, whose lives would be much easier having access to all kind of interfaces.

As a matter of fact, over 2 billion people worldwide have different types, degrees, or combinations of disability, literacy, digital literacy or aging related barriers that impede or prevent them from using ICT [1]. Society cannot afford to have this cumulatively large percentage of people offline, yet there is no way to reach them with the current model. Thus a new model needs to be implemented that would trigger the proper accessibility settings of each interface, based upon the respective needs and preferences of the user. This model is being prepared by the GPII [2] and has been partially developed in Cloud4all EU project [3], which scope and results we will elaborate in the current paper.

Cloud4all has initiated the implementation of GPII's scope, which is to provide to everyone and everywhere the settings they need in order to use any ICT. In Cloud4all specifically the focus was ICT that are more frequently used, i.e. PCs and laptops with Windows and Linux, simple and android phones, Windows tablets, TVs and vending machines, covering a wide range of public and private devices.

One of the basic research topics in Cloud4all was the mapping of the needs and the preferences of the users with the settings they will get. But what are the needs and the preferences and what is the difference between them? First things first, the needs of a user are translated into settings without which they cannot interact at all with an interface (i.e. text to speech for blind users), while the preferences are translated into settings the users prefer to have, but they can interact with a device, even if these settings are not available (i.e. a specific speech rate for blind people).

During Cloud4all project, 3 iterative pilot phases have been realized and gave the opportunity to the research team to meet and interview more than 500 people in Greece, Germany and Spain. In this paper we present the results of the evaluation of Cloud4all in terms of mapping the needs and preferences of the users to the settings that are given to them, and the results are surprising.

2 End Users' Needs and Preferences

2.1 Problem Statement

There are a number of key problems that affect the access of all user groups to assistive technologies. There are couple of generic problems to be used as a baseline which can be deconstructed and combined in various manners in order to sketch the individual problems of each user. The key problems for which a user cannot access a device are the following:

1. Solutions are too complicated, being difficult to find, set up and adjust, especially when the systems should be used by different users.

2. Solutions don't work across all of the devices and platforms that users encounter in education, employment, travel, and daily life.

The problem statement that occurs from the aforementioned aspects is summarized in the following scenario:

> A user is trying to use a device that is not configured based on their Needs and Preferences. Then the user is trying to use a device which is configured based on their Needs and Preferences. The user cannot use the device which is not configured based on their Needs and Preferences, but he/she can use the device which is already configured before, based on their Needs and Preferences.
>
> The user cannot configure the device to fit his/her Needs and Preferences, either because he/she cannot (due to their disability) or because he/she do not know how to. It would be easier for the user if there was an automatic mechanism, which he/she could understand, with which he/she could easily login to the device he/she want to use and it would be automatically configured. It would also be easier for the user if there was a tool that would allow him/her to create an account and set his/her own Needs and Preferences than visiting the settings of each solution he/she want to use and tweak them manually.
>
> Users with disabilities are pledged to the environment in which they use the different solutions/devices. The users cannot use the devices they want under specific contexts. A mechanism that would allow the solution/device to automatically change based on the user's Needs and Preferences would enhance the user's interaction.

Thus the users' problem is twofold. On the one hand they cannot use solutions that are not configured based on their needs and preferences and on the other hand most of the users cannot configure these solutions at all, either because they are not aware of their needs and preferences or because they are not aware how to change the solution settings to match them.

The aforementioned scenario can be partially solved by creating a system that will get the needs and preferences of the user and transform them magically into settings. The question then is, if these settings really match the needs and preferences of the users.

2.2 What the Users Need

Before starting an evaluation of any kind, the first step was to gather the users and try to find out their priorities. Even in this, very initial step 4 different types of users were identified.

- The expert computer users who are totally aware of their needs and preferences, and also which are the settings they have to apply in order to satisfy these needs and preferences and get the interface they want.
- The computer literate users who are aware of their needs and preferences, and also which are the settings they have to apply in order to satisfy these needs and preferences, but they do not know how to apply those settings in the different devices.

- The computer illiterate users who are aware of their needs and preferences, but they are not aware which are the settings they have to apply in order to satisfy these needs and preferences.
- The computer illiterate users who are unaware of their needs and preferences are.

Thus, we have conducted a thorough survey involving users from all the aforementioned categories in order to identify which are the most dominant needs and preferences of the different users' categories involved in the research and prioritize the settings that we would apply.

The users where asked about some basic issues including the applications they use, the configuration they perform, the problems they confront hand the preferences/requirements they have. There were different user groups involved in this procedure (visual impaired, hearing impaired, cognitive impaired, elderly, etc.) but we will focus on the blind and visual impaired people since the finding from this group are the most interesting ones.

Based upon the results from the user surveys, the needs and preferences of the visual impaired people (including blind) are the following.

- Built-in accessibility transformation of content
- Auto-installation of OS or screen reader
- Simpler configuration
- Screen reader
- Guidance methods
- Braille and tactile symbols
- Audio descriptions
- Only-text version of content
- Voice dialling
- Large font
- Key shortcuts
- High contrast
- Zooming
- Ability to overwrite css
- Screen magnifier
- Compatibility of different AT technologies
- Simpler interfaces

In order to analyse the results of the user study, a differentiation on the requirements should be made based on the weight assigned to each accessibility settings. "***Needs***" refers to accessibility settings to be applied consistently across applications and devices or in specific contexts. "***Preferences***" refers to additional accessibility options that are preferred for specific conditions, but that doesn't prevent the general usage of the product even if they affect their performance.

Needs: TTS, Braille or combinations are named by blind people, while screen enlargement options (e.g. Zoom or magnification) are the most named feature between low vision users.

Preferences: In this category participants claimed several settings that detail a basic need. For example, if one user set TTS as a need, it is probable that settings as voice adjustment, speech rate, punctuation, etc. appear as preferences.

Required accessibility settings for specific contexts: Users would want to activate accessibility settings always or conditionally, and these condition could depend on content, application or device attributes. For example, TTS would want to be activated always or just under the conditions of (1) reading large texts, (2) when using text processing software but not with other applications, (3) TTS on mobile phones but not in PCs applications. The requirement could also depend on the preferred AT product (e.g. prefer to activate ZoomText over Windows magnifier). Finally, there could be also dependencies between preferences (e.g. do not activate magnification, if TTS is activated).

2.3 Transforming User Needs into System Settings and Moving Between Different Devices and OSs

While the idea of transforming needs and preferences into device settings seems very clear and straightforward, the same does not stand for its implementation. There are a number of barriers which were identified as the development and the evaluation of the research was evolving.

The first and more important barrier of all the research is hiding inside its own idea and scope. Thus, the aim was to trigger existing accessibility features of the devices and not to create new accessibility features. This scope ensures the scalability, flexibility and transportability of the accessibility features, but it lacks of accuracy of the transformation of users' needs and preferences.

Lets' describe this using a scenario. There is a blind user who wants to use a public laptop in a library. This user is using JAWS and has clearly stated at the users' survey that he/she needs some kind of text to speech to use a device. But what happens when the device he/she wants to use does not have the screen reader the users is familiar with? The decision here was obvious. We will provide another screen reader which is available and installed in the device! But what if there is no screen reader installed in the device? Then we will either redirect the user to a web based screen reader or try to install automatically an open source one. In any case though, the result will be that the user will have to interact with a screen reader which he/she is not familiar with. Will this be perceived from the user as a flaw of the system and a reason not to use it, or it will be perceived as a benefit since at least he/she can use a device which would not be accessible in other case? We will see this in the next section, where we provide the results of the evaluation with end users we will present the users reactions on these issues presented above.

Another issue that was faced when working at the transformations of needs and preferences into system settings was the different settings each device supported and the way each setting was expressed in each device. For example a simple setting that is useful for people with visual impairments is the font size. The font size has different expression and range in Windows and different in Android mobile phones. Thus a user who has declared that he/she wants to have a big font size, he/she will not experience the same size throughout all the devices, and this means that in some devices where the text size is not beg enough additional settings might have to be enabled in order to use the device, i.e. zoom or screen reader.

And here lays all the intelligence of the system. These complex issues that emerge from such a simple scope are to be solved by the matchmakers of the system which are smart algorithms that map the needs and preferences of the user to the different settings of the devices, as well as the setting themselves with each other. In this way when the user states his/her needs and preferences the system can identify to which settings for each device these needs and preferences are reflected. But does this satisfy the user after all?

3 Evaluation of the Transformation of the Needs and Preferences of the Users into Device Settings

3.1 Evaluation Methodology

In the evaluation with end users we were called to verify the following research question:

> How will the solution foster digital inclusion by improving user experience, in comparison to the current way of performing a common task in different, familiar or not, non-personalized solutions?

Based on this research question, the following hypotheses had to be verified.

H1: **Influence on UX when configuring a solution**

$H1_0$: The solution doesn't improve users' experience when configuring a solution.

$H1_1$: The solution improves users' experience when configuring a solution.

H2: **Influence on UX when performing a common task in familiar, non-personalized, solutions**

$H2_0$: The solution doesn't improve users' experience when performing a common task in familiar non-personalized, solutions.

$H2_1$: The solution improves users' experience when performing a common task in familiar non-personalized, solutions.

H3: **Influence on UX when performing a common task in non-familiar, non-personalized, solutions**

$H3_0$: The solution doesn't improve users' experience when performing a common task in non-familiar, non-personalized, solutions.

$H3_1$: The solution improves users' experience when performing a common task in non-familiar, non-personalized, solutions.

The scenario that was be performed by the users in order to validate the hypotheses is the following:

- The user visits a public library and wants to use a desktop PC available to find some information.
- The user wants to visit a specific Clouda4ll webpage.

- The user can configure the device in order to have better access.
- When the task is completed the user is asked to use the system to perform a similar task.
  - The user configures the device using the system.
  - The user performs the task using the system.
  - The user keys out (log out) from the system.
- The user visits a friend's house and wants to perform a task to the existing device there.
  - The user wants to perform a task.
  - The user can configure the device in order to have better access.
- The user performs the task (device dependent) using the system.
  - The user keys in (log in) the system.
  - The user performs the task using the system.
  - The user keys out (log out) from the system.

The detailed scenario that the end users performed is comprised by the following tasks and subtasks.

Task 1: Perform a common task (a1) in Platform A with no configuration

Subtask 1.1: Try to perform the task a1 successfully, allowing the manual configuration of the device (depending on what the user wants)

Task 2: Configure the device using Cloud4all

Subtask 2.1: Identify the needs and preferences using the Preferences Management Tool (PMT)

Subtask 2.2: Create a Cloud4all account

Task 3: Perform a common task (a2) in Platform A with Cloud4all configuration

Subtask 3.1: Try to perform the task a2 successfully

Subtask 3.2: Optimise the needs and preferences using the PMT or manually

Subtask 3.3: Key-out (log-out) from Cloud4all

Task 4: Visit Platform B and perform a common task with no configuration

Subtask 4.1: Try to perform the task b1 successfully, allowing the manual configuration of the device (depending on what the user wants)

Task 5: Perform a common task (b2) in Platform B with Cloud4all configuration

Subtask 5.1: Key in (log-in) to Cloud4all

Subtask 5.2: Try to perform the task b2 successfully

Subtask 5.3: Optimise the needs and preferences manually

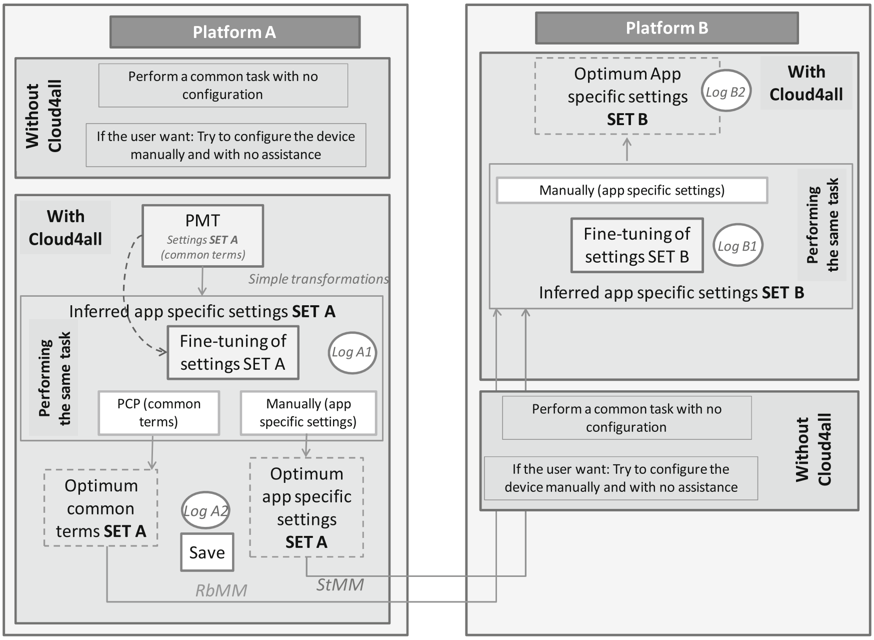


Fig. 1 Cloud4all 2nd evaluation phase. Auto-configuration scenario

While the user performs the aforementioned scenario, the different technical components will be functioning in the backend. The figure below illustrates the flow of the scenario, the tools that participate and the different logs that will be kept for the validation of the Cloud4all functionalities that participate in the scenario Fig. 1.

3.2 Evaluation Results

The first thing we asked the users at the evaluation was if they would like to make any changes to the Windows system interface. Only 38 of 84 participants (45 %) were positive in making changes in the interface, while the rest 46 users (55 %) didn't. From these 46 users, 22 % (most of them hard of hearing or elderly people) claimed to have no need of any especial configuration. On the other hand, the main reason for not making changes was "not knowing how to make configurations", 25 % of the users claimed. Additional reasons for not changing configurations included the unavailability of the configurations required (2 %) as well as others (such as "I need configurations for long tasks but not for this scenario" or "I will use the built-in browser zoom for this task") (6 %).

The performance of the users during configuration made clear that there is a difference between those users with specific needs and those that only had preferences:

- Those users with clear interaction needs, such as blind users needing a screen reader or low vision users needing a magnifier, were really motivated to make changes in the system. However, the first challenge for configuration was to find and launch the screen reader or magnifier. For these users it is a prerequisite that the system should have the AT installed. Most of the users weren't able or didn't know how to configure the ATs by themselves. Only those experienced users tried to launch and configure the AT.
- Those users that only had preferences that are not essential for the interaction, as elderly that get slightly benefited from increases in font size, only made changes if they had high computer skills. For this group there was an initial surprise when discovering the Cloud4all concept and it may provide added value by making easier the configuration procedure.
- Finally, users that neither had needs nor clear preferences were able to perform the tasks with the standard configuration of the computer. For those users, it was not clear what would be the benefit of Cloud4all beyond the initial surprise of experiencing the auto-configuration.

According UX and transformation of settings, the results showed that Cloud4all improves users' experience when performing a common task, both in familiar and non-familiar solutions. First, in a familiar solution as *Windows* systems, it was found that the users were generally more successful performing common tasks, perceived them as easier and felt more autonomous and competent. Second, it was found that the performance and user experience with unfamiliar solutions was particularly poor without Cloud4all, but it significantly improved when auto-configuration was applied. Notice that the general results with *Windows* are much better than those obtained with solutions that were mostly unfamiliar to the participants (*Linux*, *Android*, and *Java phones*). However, it should be taken into account that in the case of unfamiliar systems some users were not able even to access the solution before applying auto-configuration. So, the users were in general satisfied with the transformation of their needs and preferences into device settings, even if some cases they were not met their expectations. The fact that they could use a device they could not use otherwise, has very positive effect on their perspective.

4 Conclusions

One of the main purposes of user research in Cloud4all was to understand the requirements and difficulties of a broad variety of individuals when using ICT products in their daily live. In a user study conducted with more than 500 users in 3 countries, we explored the current difficulties and limitations users are facing when assistive technologies or customized accessibility settings are needed. Moreover we were investigating if users can actually specify their needs and preferences and finally if the given setting enhance their user experience by reflecting properly their needs and preferences [3].

Thus, this paper focuses on the identification of the needs and preferences of the users, and how sufficient this is, as well as to the transformation of these needs and preferences into device settings and if these satisfy the users. These questions reveal if each individual really knows what he/she requires in order to use ICT and, on the other hand, if there are indeed individuals that have no specific requirements. Based on the collected data, visually impaired participants, including low vision and blindness, have a basic understanding of the assistive technologies and accessibility settings they require to interact with their ICT products. But there are other types of users that are not so aware of the accessibility settings they could require either because they are unaware or because they have low computer literacy.

The main findings of the evaluation are the following:

- There is a wide variability in the way users prioritize settings to be applied and there exist several conditionals for activating such settings or not. Therefore inferring the optimal configuration for a certain user is not a straightforward process and the full complexity of the context should be taken into account.
- Currently, users' found very difficult to configure a familiar or non-familiar system they encounter and want to adapt to their needs and preferences. Cloud4all tools benefit users by making the configuration process easier, improving their autonomy and competence when making the adaptations in the system.
- Cloud4all auto-configuration allows users to better and easier perform common tasks, and make them feel more autonomous and competent in both familiar and non-familiar systems.

The results presented in this paper are very promising. It seems that the users really need a system that provides them with basic accessibility features and enable them to use a device, especially if they could not use it before. Additionally, it reveals points where further research needs to me made in order to be covered. These topics are more related to the allowing the user to discover and acknowledge his/her own needs and preferences, without having to be aware of them beforehand or without the need of being computer literate.

References

1. EU project Prosperity4all. http://www.prosperity4all.eu/
2. Global Public Infrastructure Initiative. http://gpii.net/

3. Loitsch, C., Chalkia, E., Bekiaris, E., Weber, G. Tailored versus prioritizes configuration towards accessibility. A study on weighted preferences. In: Stephanidis, C., Antona, M. (eds.), Universal Access in Human-Computer Interaction. Design and Development Methods for Universal Access (pp. 246–257). Springer, Switzerland (2014)

Ergonomics in Clothing: Importance of Thermal Comfort in a Typical Brazilian Refrigerator of Beef Industry

Maricielo Well Quispe Núñez, Iracimara de Anchieta Messias and Carolina Lotufo Bartholomei

Abstract Human exposure to uncomfortable temperatures has been of concern in the last decade, since in these conditions the frequency of occupational accidents and diseases increases in most cases. This study discusses and determines the aspects of usability and ergonomics related to thermal comfort; and the role of clothing as a protective agent against the risks caused by thermal discomfort at low temperatures in workers of a typical Brazilian Refrigerator of beef industry. For this, there were interviewed all industry workers affected in the refrigerator, and were analyzed the results through computer software. The result will show the characterization of the real workers' situation in a typical Brazilian refrigerator, relating to thermal comfort, bringing ergonomics clothing as a principal issue to be analyzed. Consequently, there were observed aspects such as comfort, usability and efficiency to demonstrate the consequences generated in the health and well-being of workers exposed to cold.

Keywords Clothing · Ergonomics · Refrigerator · Thermal comfort

1 Introduction

Due to Brazilian tropical climate, the activities carried out at low temperatures are restricted to a few sectors, especially the meat industry. That is why the researches and studies on occupational environments at low temperatures are still scarce [1]. According to Laville [6], there are several work stations undergoing significant

M.W.Q. Núñez (✉) · I. de Anchieta Messias · C.L. Bartholomei
University of the State of São Paulo, Roberto Simonsen Street 305,
Presidente Prudente—São Paulo, Brazil
e-mail: mariwell888@hotmail.com

I. de Anchieta Messias
e-mail: iracimaramessias@gmail.com

C.L. Bartholomei
e-mail: carolinalotufo@fct.unesp.br

M. Soares et al. (eds.), *Advances in Ergonomics Modeling, Usability & Special Populations*, Advances in Intelligent Systems and Computing 486,
DOI 10.1007/978-3-319-41685-4_26

thermal limitations among them are: the work outdoors, hot or cold climatic zones, and also local air-conditioned due to technical requirements or non-air-conditioned due to other factors. The market has an increasingly demand, such companies that seek to secure a competitive position by adopting strategies that highlight the worker's health and welfare. Since human labor has been significantly influenced by environmental conditions, the temperature is an important point of attention. For this, must be known that the thermal comfort is the condition of mind that expresses satisfaction with the thermal environment [1].

According to Goldsmith [3], the ability at work exposed to low temperatures, depends on two features that occur in the brain and limbs. Through brain may experience symptoms of mental confusion and difficulty in coordination, while in the limbs may occur manifestations of paralysis and imprecision in movements. The heat loss in the feet and other parts of the body should be avoided, since it is extremely uncomfortable and, also provides the onset of diseases such as articular inflammations and rheumatic diseases [5].

Major risks involving exposure to cold are cooling, predisposition to accidents, predisposition to respiratory diseases, worsening of pre-existing rheumatic and vascular diseases [7]. The thermal sensation varies with each person, so each has a certain temperature range in which is feeling comfortable, but it depends mainly on the clothing that is using and the level of physical activity performed at the time, [5].

According to Wisner [8], ergonomics is a set of scientific knowledge relating to man and necessary for the design of products and tools, machines and apparatus in order to use them with maximum of comfort, security and effectiveness. The human thermal comfort requirements are then related to the functioning of the body while producing and loosing amounts of heat to the environment through the heat exchange; and also to the clothing that covers the body, that is an indicative of thermal resistance to heat exchanges [4].

According to Gomes [4], when the body is clothed, the heat generated and dissipated can be prevented from reaching the environment, since it needs to cross the barrier imposed by the tissue, both in relation to its type frame—construction and to its thickness. As well as, depending on the case, for different tissue overlays, when it is covered with more than one clothing. The use of many clothes can cause excessive sweating with heating body, requiring more organism activity to maintain thermal balance [2].

Gallois [2] points out that the clothes considered appropriate to cold environment should be thermally resistant and able to release the sweat produced by the body, being the product of intense physical activity, and deposited on the skin. In the moments that slow down the rhythm of activity, the wet skin promotes cooling sensation with the evaporation of sweat causing discomfort.

Thus, it is essential to note the importance of clothing use as an agent of protection at low temperature conditions and how ergonomics seeks solutions to this discomfort.

2 Methodology

This study is characterized as a qualitative and quantitative research, since there were analyzed ergonomic aspects relating to clothing uses at low temperature conditions, with emphasis on the study of its ergonomics relating to thermal comfort. The information obtained came from workers exposed to temperatures below 10 °C in a refrigerator located in the municipality of Presidente Prudente of the state of Sao Paulo. The refrigerator studied serves the domestic market which is composed by wholesalers, supermarkets, chain restaurants and steakhouses, and also to the foreign market that reaches more than 150 countries in the most demanding markets such as the European Union, Russia, Asia, Africa, Middle East, etc.,

The company currently has 70 % of workers in the productive sector. The target population was the total number of workers exposed to cold risk agent during their daily work activities, which are located in the boning sector. This type of approach has the great advantage of accuracy in the quality of the answers; this is because the margin of error is theoretically zero, since all people is interviewed. Data collection was conducted between September and December 2015, through a questionnaire employed by Buzanello [1] in her dissertation submitted to the Federal University of Santa Catarina for the degree of Master in Production Engineering focused in Ergonomics, entitled “The influence of environmental variables of a south subtropical refrigerator on workers exposed to low temperatures”. This questionnaire has been chosen due to the similarities of goals, and was adapted to emphasize the effects at low temperatures in order to improve the quality of data obtained.

For data organization in order to obtain measures of variability and position, the results obtained in the characterization of clothing usability as a protective method in low temperature conditions were subjected to a descriptive statistical analysis with Excel Program (2013 version) and Epiinfo (3.5.2 version). For this, there were studied the usability and efficacy of protection provided by clothing, the risk of freezing, lack of strength in hands, ache in the hands and diseases related to low temperatures.

This project was submitted to the Ethics Committee in Research and approved with the number 549.555, thus, the present study does not violate ethical principles according to CNS Resolution 466/2012.

3 Results

During the second half of 2015 year, there was applied an interview with the total population in the boning sector, which is composed by 55 employees. In the population studied, composed by 53 % of men, the aspects of ergonomics in clothing were questioned.

Table 1 Clothing used in boning sector and the percentage of workers who use them

Parts of the clothing	Percentage (%)
Blouse	61.8
Helmet	98.2
Boot	98.2
Bonnet	96.4
Pants	98.2
Shirt	94.5
Thermal hood	14.5
Steel mesh apron	10.9
long steel mesh sleeve	34.5
Glove latex	76.4
PVC aprons	74.5
Short sleeve of steel mesh	25.5

With data, it was possible to observe that 78 % of workers consider their clothing as sufficient to protect. It was noted that the helmet, the boot, the bonnet, pants and shirt are the clothes used in more than 94 % of the population since the blouse, thermal hood, glove latex and PVC aprons are used only between 14 and 76 % of the population, being all of them required and offered by the company every day, but not all are used (Table 1).

In addition, the steel mesh apron, the long steel mesh sleeve and short sleeve of steel mesh, which are compatible clothes, mandatory with only one type of task carried out in the sector that needs more effort and therefore they are used for 10–34 % of the population studied. It was also observed that 80 % of workers consider comfortable clothing, this suggests that there are other causes that make the workers to do not use the complete clothing during working hours, so it was also determined its sufficiency. Next, a contingency table is presenting the relation between the variables clothing efficacy for protection and clothing comfortability (Table 2).

Based on Table 2, it appears that 70 % of employees consider their clothing as sufficient and comfortable to working conditions, 9 % consider their clothing efficacy, but not comfortable, 7 % did not find the clothes efficacy, just comfortable and 22 % consider clothing as insufficient to provide protection and also uncomfortable.

Because the hands are the part of the body that are most used in this type of work, the use of gloves during the work was consulted, and it was observed that 55 % does not use gloves, and 96 % of those who use them support that the use is

Table 2 Relation between the sufficiency of clothing and its comfort

		Clothing sufficiency		
Comfortable clothing		Yes	No	Total
	Yes	70.37 %	9.26 %	79.63 %
	No	7.41 %	12.96 %	20.37 %
	Total	77.78 %	22.22 %	100.00 %

appropriate for the task performed. Based on this observation, there were asked about the negative effects occurred in the hands because of low temperatures, so it can be noted that about 54 % of employees denied feeling any kind of negative effect on hands. However, 27 % reported tingling or numbness, lack of agility 15 and 4 % insufficient strength. It was also found that 29 % feel cold in both hands, 34 % said they feel cold in the hand that holds the product, 18 % said they feel cold in any specific part and only 13 % argue that feel cold in the hand that holds the knife. The highest concentration of responses was 56 %, which declared feel cold feet.

Through the survey, it was found that most of the answers refers to the environment of work as "cold", accounting a total of 44 % of all the answers, noting that this thermal sensation occurs despite protective clothing are used. In addition, 25 % of people declared the environment as 'very cold', while 18 and 13 % judged as 'slightly cold' and 'neutral', respectively. It is important to mention that 11 % of employees felt the trembling body during working hours, and 4 of every 7 workers tremble at the beginning of the work, presenting some sweating in the middle or at the end of the job.

The lack of thermal comfort with the use of clothing can be seen reflected in the lack of use, and this can cause illness and accidents at work according to the literature, it was found that 24 % had suffered some kind of accident during the period of job. Among the causes of accidents, the prevailing was cuts by knife, occurred in 11 of every 13 workers. The members most affected by this accident cause were mainly hands and fingers. The other members are parts of the arm. There were also determined the proportion of the target population with some kind of disease, according to the medical diagnosis and self-evaluation of the worker, it is important to make clear that all diseases were not necessarily incurred during working time but the low temperatures can intensify them (Fig. 1).

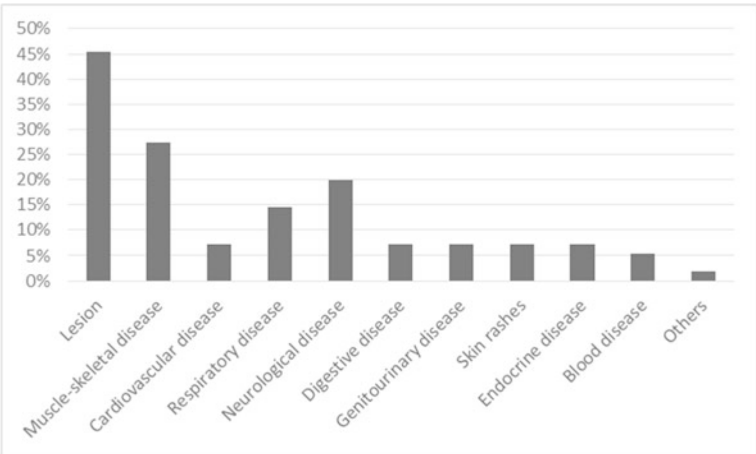


Fig. 1 Frequency of diseases in the population studied

From the results, it was found that 45 % of workers has some kind of lesion. The other most reported diseases were the muscle-skeletal, presented in 27 % of workers, respiratory and neurological diseases, founded in 15 and 20 % of workers respectively.

4 Conclusion

According to the results, in a population composed by approximately equal proportions of men and women, it was concluded that ergonomics in clothing, which considers the frequency of use and efficiency for protection and comfort, influence the thermal comfort of workers during their period of work and they can bring consequences as accidents and occupational diseases in most cases. Initially it is important to highlight that clothing that would be favorable to have an acceptable thermal comfort, such as a blouse, heat hood and sleeve latex, are used with less frequency (between 14 and 76 %).

Looking for the causes that make workers to use just some of the clothing necessary at these conditions, there was suspected that maybe the clothes were not comfortable enough. So that, the contingency table was needed to determine how comfortable and sufficient to protect the clothes are, then we noted that only the smallest part of the population considers clothing as uncomfortable and insufficient to protect against the negative effects of the cold. Because the majority of the population feels clothing comfortable enough, there are probably other causes that make workers to use just some of the clothing necessary during working.

Because the hands are the part of body that is used with more frequency in such work, it was found that approximately half of the population studied does not wear gloves (latex and steel mesh) and about the third part of the total population consider the use of clothing appropriate for the tasks at work. It is important to note that about half of them affirm that do not feel any negative effect on hands; however, those who confirm the opposite, mentioned some symptoms like tingling, numbness, lack of agility in the hands and more incidence of cold feeling in the hand that holds the product and feet. This means that clothing really works as a protective agent against low temperatures, since about half of the workers use gloves, guaranteeing that they do not feel negative effect on the hands. Besides this affirmation, more than 60 % of employees insist the environment is 'cold' or 'too cold', showing discomfort with the environment. So, the lack of the complete clothing use could be the reason of thermal discomfort causing negative effects.

An efficient clothing is reflected by the kind of responses that the body presents, so in this study we found that 4 of every 7 workers tremble at the beginning of the working day, presenting some sweating in the middle or at the end of their activities. It is important to note how the clothing material is acting on workers and it should be considered the magnitude of the effort exerted by the workers during their activities. Besides the properties of clothing material, negligence in the use of clothing during working hours can cause major imbalances in the body, such as we saw here.

Among the consequences generated by exposure to physical temperature risk agent, occupational accidents stand out, which have occurred in less than the third of the population studied, most of them were courts with knife in the arms, being that clothing is also designed to protect the cut by accident, still some significant exceptions have happened. Occupational diseases are also an important consequence, in this study we observed that about half of the workers has some kind of lesion, moreover, the musculoskeletal, respiratory and neurological diseases are the most frequently, its importance is relevant since they may have appeared because of the low temperatures and may worsen under these conditions, decreasing worker's quality life.

Acknowledgments The authors thank the Fundação de Amparo à Pesquisa do Estado de São Paulo (FAPESP) by the financial support.

References

1. Buzanello, M.R.: Influence of the environmental variables in south subtropical climatic unit refrigerator on workers exposed to low temperatures. Dissertation of Master in Production Engineering, Federal University of Santa Catarina, Florianópolis (2003)
2. Gallois, N.S.P.: Analysis of stress conditions and thermic comfort under low temperatures in refrigerator industries of Santa Catarina. Dissertation (Master of Production Engineering), Federal University of Santa Catarina, Florianópolis (2002)
3. Goldsmith, R.: Cold and work in the cold. In: Encyclopedia of Occupational, International Labour Health and Safety Office. Geneva, Switzerland, pp. 504–507 (1989)
4. Gomes, M.: Analysis of thermic postman perception of CDD-Londrina in relation to clothing used in hot environment. Dissertation of master in Industrial Design in Ergonomics, Arts and Communication of the Paulista State University, Bauru (2007)
5. Grandjean, E.: Manual of Ergonomics: Adapting the Work to People, 4th edn. Bookman, Porto Alegre (1998)
6. Laville, A.: Ergonomics. Translation: Márcia Maria Neves Teixeira. São Paulo: EPU, Ed. of University of São Paulo (1977)
7. Soares, A.C.C.S.: Retrospective study of musculoskeletal complaints in refrigerator workers. Dissertation of Master in Production Engineering, Federal University of Santa Catarina, Florianópolis, SC (2004)
8. Wisner, A.: Inside of work: ergonomics: methods and techniques (Flora Maria Gomide Vezzá). FTd: Oboré, São Paulo (1987)

Part III
Ergonomics and Design for All

Impact of Advance Fabrics on Human Biomechanics: Example of Anti-fatigue Mats

Redha Taiar, Tareq Z. Ahram, Nicolas Gardan, Alexandre Schneider and Dimitra Sifaki-Pistolla

Abstract Health and individual's wellbeing is influenced by a range of factors such as social, cultural, economic, psychological and environmental. For instance, people spend approximately 8 h per day at work, where they are exposed to multiple stressors that have a negative impact on their health. This increases the risk of disease, especially for those who present low levels of physical activity per day. The objective of this study is to assess the impact of new generation of advanced 'smart' material on body balance at work. Studying the body upright position and balancing by utilization of technological mats helps professionals in their daily life through decreasing muscular problems, especially fatigue. This is due to the increased frequency and repetition of movements that are performed by professionals over extended periods of time. Another objective of this study is to validate model prototypes that improve ergonomics at work, as well as optimize users' comfort; a new anti-fatigue mats by Notrax®. A total of 25 professionals from different age groups participated in the study which took place for a period of six

R. Taiar
Université de Reims Champagne Ardennes, Campus Moulin de la Housse,
Reims Cedex, France
e-mail: redha.taiar@univ-reims.fr

T.Z. Ahram (✉)
Institute for Advanced Systems Engineering, University of Central Florida,
Orlando, FL, USA
e-mail: tahram@ucf.edu

N. Gardan
CAD and CAE R&D Center DINCCS "Micado", Pôle de Haute Technologie,
Charleville-Mezières Cedex, France
e-mail: nicolas.gardan@dinccs.com

A. Schneider
Université de Reims Champagne Ardennes, Charleville-Mezieres Cedex, France
e-mail: alexander.schneider@univ-reims.fr

D. Sifaki-Pistolla
Clinic of Sovial and Family Medicine, Faculty of Medicine, University of Crete,
Heraklion, Crete, Greece
e-mail: spdimi11@gmail.com

M. Soares et al. (eds.), *Advances in Ergonomics Modeling, Usability & Special Populations*, Advances in Intelligent Systems and Computing 486,
DOI 10.1007/978-3-319-41685-4_27

months. A dysfunction in balance was observed in professionals who didn't use mats. Dysfunction in balance can cause pathologies, strain and fatigue therefore disorders due repetitiveness. Additionally, a significant increase of balance was observed for those who used the mats in comparison of those without mats ($p < 0.05$). Significant variations were also observed between the different mats and their specifications ($p < 0.05$). Utilization of mats helps professionals on their daily life by decreasing joint stresses and optimizing body balance.

Keywords Biomechanics · Smart material · Body comfort · Body balance · Optimization

1 Introduction

Assessing posturography to quantify postural control within working settings has been rarely studied in the literature. The concepts, methods as well as the analysis or techniques that are used to assess human mechanics represent major economic challenges. These concepts should be approached and developed by integrating physical sciences (metrology, systems mechanics and electronic complexes), information technologies and life sciences (materials, tissue, organs and parts); this represents the interface between biomechanics and medicine. The posture analyses measures the impact of material on balance and optimize the body position at work. Through the record of the displacement of the center of pressure [1–3] balance can be quantified. This represents an important function in the organization of the static and dynamic posture of professionals. Additionally, it permits the postural control and its maintenance in the three-dimensional space. Body balance is influenced by visual information, vestibular and the somatosensory system. These three pieces of information are essential and allow the maintenance of the body balance, its adjustment and optimization.

The organization of the static and dynamic posture is allowed by the complementarities of information which the human body perceives permitting the compensation between internal and external stresses. However, when information is defective, body balance is disturbed and affects professionals' ergonomics. Te-Hsin and Kleiner [4] defined it as an applied science that co-ordinates the design of devices, systems and physical working conditions with the capacities and requirements of the professionals. For example Bongers et al. [5] stress that by addressing traditional and environmental risk factors, it can keep professionals injury-free. In both definitions, mechanical human behavior at work is at the focal point. This is due to the fact that working conditions affect and often determine ones overall quality of life. There are various factors which affect professionals, especially those who are standing for long periods of time or those who have any type of physical disability. It is sometimes hard for an able-bodied person to understand what it feels like to stand for long periods of time and how your life is affected if you are not standing in the right position with a good balance. This is because able-bodied persons can re-adjust and change their position before getting too uncomfortable which is often an unconscious movement. Therefore, getting the right position by increasing knowledge is extremely important. Nowadays, professionals have various disorders related to feet, legs and back. Impact of multiple years' work may possibly develop to musculoskeletal disorders (MSDs). For, 90% of disabled older professionals had MSDs [4, 6]. Treatment of the problem costs tens of billions of dollars according to Praemer [7]. Furthermore, Professionals' injuries could result in (long term) absenteeism, decreased productivity or even liability claims. These factors have a negative impact on costs. In Taiar [8], mats cushion the fall of fragile products, tools and other objects. Mats also protect the floor from these falling objects.

Less damage reduces costs. Cold feet contribute to fatigue; mats $A = \pi r^2$ an insulating barrier between professionals' feet and cold factory floors. Mats reduce transmission of noise and help neutralize machine vibrations. The aim of this study is to assess and measure the discriminate parameters of balance of professionals with disequilibrium and pathologies at work. This will be achieved through the optimization and validation of prototypes destined to improve ergonomics at work, to increase the comfort of the walking users, as well as to decrease the joint stresses. The present study was driven by the following hypothesis: postural strategies can be differently affected by the utilization of smart mats and depend on the degree of balance dysfunction of each professional.

2 Materials and Method

Twenty five healthy professionals (15 males and 10 females) aged 42.76 ± 9.31; with 167.68 ± 8.40 height; 74.76 ± 8.85 weight and experience years 15 ± 10.64 were enrolled in the study. The main exclusion criterion was the existence of professional's previous history of musculoskeletal problems. Therefore, professionals were asked to fill out a questionnaire about delivery, early pattern of locomotion, physical activities, and diseases of the motor system and previous history of frequent otitis which might influence balance control. All professionals had normal capacities without antecedent deficit or pathologies.

3 Characteristics of the Materials

3.1 How Matting Works

Cushioning effect stimulates continuous micro movements. Ergonomic design spreads weight and corrects balance. Beveled edges prevent tripping on the mat. Slip resistant surface prevent slips and falls (see Fig. 1). Different tests have been

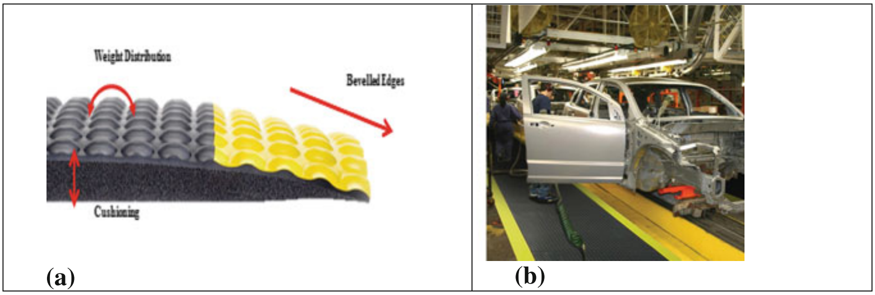


Fig. 1 **a** Description of the mat. **b** Example of utilization of the mat in motor industry

utilized in order to describe mats and their contribution in terms of accelerated wear test, protection of electrostatic discharge, static coefficient of friction, graves tear strength and the compression deflection comparison.

Three types of mats were selected in this experimentation:

3.2 *Cushion Trax*

Ergonomic benefit derived from 14 mm thick worker platform comprised of a long wearing top surface laminated onto a resilient microcellular vinyl base for maximum durability and fatigue relief. Diamond plate pattern provides traction while allowing twist turns. Slip resistance R10 according to DIN51130 and BG-rule BGR181. Tested and certified by the National Floor Safety Institute (NFSI). Featured with RedStopTM slip resistant backing that prevents mats from shifting. Available yellow borders along sides comply with OSHA code 1910-144. Beveled edges on all four sides risk of tripping. UniFusion^{TM} technology, engineered to resist in the harshest work environments (Fig. 2).

3.3 *Cushion Ease Solid*

Heavy duty rubber tiles of 91 cm × 91 cm can be easily assembled for coverage of large areas or individual work stations. Ergonomic benefit derived from a 19 mm thick worker platform with a closed anti-slip pebble structure surface for maximum anti-fatigue comfort in dry industrial environments. These interlocking mats allow on-site customization. Square snap together units can be assembled effortlessly and laid out from wall to wall or as islands, in any direction or shape. Super anti-fatigue properties due to its unique design underneath and high quality resilient rubber compounds. Compatible with patented MD Ramp System^{TM} for smart safety beveling solutions, allow out and inside corners (Fig. 3).

Specifications:

- 4.7 mm PVC top surface permanently bonded onto a 9.3 mm resilient backing of microcellular vinyl.
- Overall thickness:14mm
- Weight:5.5 kg per m^2
- Coefficient of friction NSFI certified.

Fig. 2 Cushion Trax mat with specifications

Specifications:

- Heavy duty rubber compound,
- Overall thickness: 19 mm
- Weight: 12.7 kg per m_2
- Slip resistance rating R9 according to DIN 51130.

Fig. 3 Cushion Ease Solid mat with specifications

3.4 Mat Skywalker

This high quality type polyurethane foam is reputed for its ultimate comfort and longevity properties. Its key characteristic of high thermal insulation performance is owed to a uniform closed cell structure wherein gas remains trapped. Integral skin adds to the compression force deflection properties (>120 according to ASTM 3574C), provides resistance to wear and is non-porous. Unique workplace mat guarantees optimal ergonomic effects in stationary standing positions. All four sides have beveled edges to minimize tripping hazards (Fig. 4).

Specifications:

- High quality polyurethane foam
- Overall thickness: 14mm
- Weight: 4.8kg per m^2
- Hardness: 25 Shore A, according to DIN 53505,
- Resistance to temperature: -40° C + 80°C.
- Slip resistance rating R11 according to DIN 51130 and BG-ruleR181.

Fig. 4 Mat Skywalker mat with specifications

4 Data Acquisition

The 'Zebris' foot pressure platform [9–11] was used in the current study. This platform that contains a large number of sensors enabled the authors to quantify the dynamic and static pressure executed by the feet. This pad is equipped with 32 × 47 sensors (a total of 1504). One sensor is 1 cm^2, has a precision of 0.5 N/cm^2 and an acquisition frequency of 60 Hz [11, 12]. This experimentation aimed to observe the evolution of the foot pressure after a defined movement. The subject keeps an upright position on the 'Zebris' platform. Through a color gradient, the authors observed simultaneously the evolution of the pressure made by the foot surface in contact with the sensors (from blue to red: pressure is increasing) (Fig. 5). The results obtained in a static position represent the keeping of an upright position and the resulting position characterized by the actual working situation in front of the workstation. During this experiment the platform was positioned on three different anti-fatigue mats (Fig. 5). The test was to stand upright for 3 min. The evolution of foot pressure and any signs of fatigue were recorded for one minute and the impact of 7 working hours on the mechanical behavior of the user was quantified. To increase reliability of the results, multiple tests were done, using different mats for better adaptation (Fig. 5). The same experimental procedure was also used for the dynamic analysis.

5 Statistical Analysis

The analysis was performed using the SAS v9.1.3. The main focus was given on the description of the posturologically relevant variables. These are mentioned, as follows:

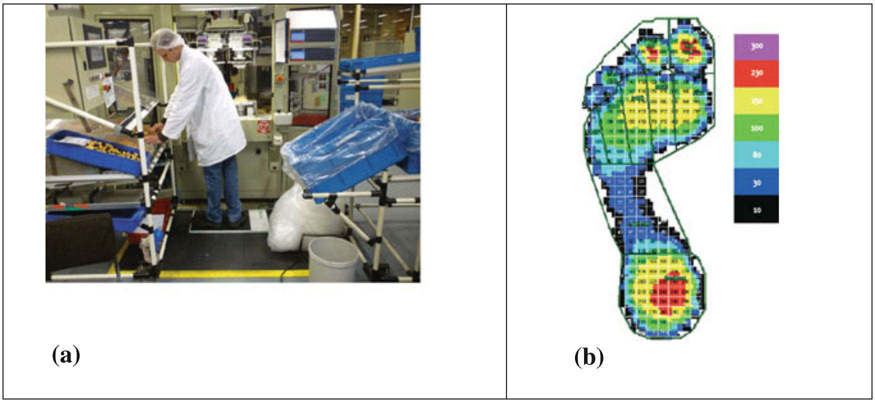


Fig. 5 **a** Mats characteristics, body position of worker and the force plate used for the pressure measure with Zebris. **b** The pressure under foot distribution

– surface of the stabilograph,
– length of the stabilograph,
– length of the stabilograph in the medio-lateral and antero-posterior directions,
– average medio-lateral deviations of the worker,
– average antero-posterior deviations.

Additionally, statistical variations were assessed using the Wilcoxon test, while all tests were performed at confidence level of 0.05.

6 Results and Discussion

6.1 Mats Analysis

6.1.1 Accelerated Wear Test

A circular test specimen 8 inches in diameter is subjected to the action of a set of rollers under a specified load. After each pass of the test sample beneath the roller bed, a ratchet mechanism rotates the sample approximately 10 degrees before passing the roller bed again. An assessment is made of the sample thickness as well as visual changes after a predetermined number of cycles (Table 1).

Interpretation of the results: The interpretation of this test consists in comparing the result “5”, with the rating key which is:

Table 1 Results of the accelerated wear test

Number of cycles	Original thickness	Final thickness	Thickness loss	Visual rating
6.000	0.3 inch	0.2 inch	0.1 inch	5

Conversion: 1 inch = 2.54 cm

5	Excellent: no change or negligible change
4	Good: slight change due to pile disturbance
3	Fair: Noticeable wear pattern due to pile crushing or matting
2	Poor: loss of texture and thickness due to pile crushing and/or matting
1	Very Poor: Severe pile crushing and/or matting, generally considered unacceptable

In this case the result is "5", indicating no change

6.1.2 ANSI ESD S7.1

Protection of electrostatical discharge of susceptible items This test method is used to measure the electrical resistance of floor materials. Measurements are made from the material surface to groundable points from surface to surface. Both tests are performed at varying humidity (Table 2).

Interpretation of the results: The result of the test is expressed in resistance surface to ground (Rg) and surface to surface (Rp) (surface to surface is also called point to point). The requirement for a mat to be conductive must give an electrical resistance reading of 10^4 up to 10^6 Ω. The requirement for a mat to be dissipative must give an electrical resistance reading of 10^{-6} up to 10^{-9} Ω. In other words, electricity present in the human body, that needs to be evacuated, meets with less resistance to ground in the case of a conductive mat. Dissipative mats discharge electricity albeit with a higher degree of resistance. Conductive mats are used in highly specialized environments which require a higher level of safety measures, whereas dissipative mats are used in more common work environments where static electricity needs to be evacuated to prevent damage to sensitive devices and unpleasant static shocks to professionals. The outcome of the above test meets the dissipative criteria. The most meaningful interpretation is to compare the Protection of Electrical Discharge test results of all NOTRAX® Floor Matting products.

Table 2 ANSI ESD S7.1 results

	Surface to ground with grounding cords attached RG	
	50 % humidity	12 % humidity
AVERAGE	3×10^8 Ω	2×10^8 Ω
	Surface to surface RP	
	50 % humidity	12 % humidity
AVERAGE	5×10^8 Ω	5×10^8 Ω

6.1.3 ASTM C1028-96 Static Coefficient of Friction

This test determines the static coefficient of friction of tile or other surfaces using a neolite heel assembly. A neolite heel assembly with a fifty pound load is pulled horizontally with a dynamometer to measure the force required to cause the assembly to slip. After the sample is tested, measurements are calculated and reported as the static coefficient of friction (Table 3).

Interpretation of the results: The Coefficient is the ratio of the load (50 lbs.) to the actual force required to move that load. For instance, the test is performed using a 50 lb. Stationary load. If the test results yield a Coefficient of 0.80, then it requires 40 lbs. of force to cause slippage. To relate this to an everyday application, the Coefficient holds true for any weight of load under the same conditions. A 250 lb. Load (a worker standing on a NOTRAX® matting product with a Coefficient of 0.80) would require 200 lbs. of force to cause slippage. The greater the Coefficient (the higher the number), the greater the slip resistance of the NOTRAX® Matting product. The most meaningful interpretation is to compare the Static Coefficient of Friction test results of all NOTRAX® Floor Matting products.

6.1.4 ASTM D1004 Graves Tear Strength

This test method covers the determination of the tear resistance of flexible plastic film and sheeting at very low rates of loading. The test is designed to measure the force to initiate tearing. The maximum stress, usually found near the outset of tearing, is recorded as the tear resistance in pounds (force). A section of matting is subjected to longitudinal force applied at a rate of 2 inches/min (1 Inch = 2.54 cm) (Table 4).

Interpretation of the results: The results of the test are expressed, as the pounds of force required to cause tearing of the mat. In this case, the pounds of force required to cause tearing of the mat is 16 lbs. The most meaningful interpretation is to compare the Graves Tear Strength results of all NOTRAX® Industrial Floor Matting products.

Table 3 Static coefficient of friction

Heel assembly condition	Static coefficient of friction
Dry	0.78

Table 4 Tear strength results

Sample thickness	0.4 inch
Test speed	2 inch/min
Average tearing strength	16 lbs

1 lb (lbs) = 0.45 kg

6.1.5 Compression Deflection Comparison

To assess the anti-fatigue properties of a NOTRAX® Floor Mat. Description of the Test: This test was designed to assess and compare performance characteristics of a variety of industrial matting submitted for testing. Two specific compression load levels were applied to the test samples and the deflection which resulted was measured. The two compressions are: 20 PSI 1.4 kg/cm^2; 40 PSI 2.8 kg/cm^2. It appears that, the greater the deflection, the better the anti-fatigue properties of the material. The compression load was increased to determine whether the deflection increased respectively (Table 5).

Interpretation of the results: The results of the test are expressed as "Deflection at 40 P.S.I." All results are reported in inches. To equate the results to actual usage, the following example is helpful: A 180 lb. Man has a surface area on each shoe of 12″ × 4″. At an even weight distribution of 90 lbs. per shoe, each shoe applies a compression load of only 1.88 P.S.I. The greater the deflection (the higher the number), the greater the antifatigue properties of the mat. The most meaningful interpretation is to compare the Compression Deflection test results of all NOTRAX® Floor Matting products.

6.2 *Biomechanical Analysis*

The experimentation consists in the study of the standing position of our patients through the aggregate of the trajectories of the center of pressure (COP) using a force plate device. The stabilogram surface, length (the forward and backward displacement distance during deviations in COP), lateral and the antero-posterior deviations were assessed. The obtained results show that in any test duration the feet and therefore also the body moves to keep balance necessary to maintain upright position during three minutes. Figure 6 showed the distribution of pressure underneath the foot in an upright position. We have made a recording of one minute to determine the evolution of the pressure center. The red circle shows how the latter has evolved. We notice that the pink colored points are distributed inside of this circle. This illustrates that the body moves to maintain its balance.

Figure 7 illustrates pictures taken at different moments (different time periods) of the experimentation. Several images have been taken to illustrate the difference in posture stability with and without the use of mats. We remark that without a mat there is a dysfunction in the balance of the person which can cause pathologies or repetitiveness and other work constraining factors which can accelerate the process.

Table 5 Compression deflection results

Product identification	Original thickness	Thickness at 20 psi	Deflection at 20 psi	Thickness at 40 psi	Deflection at 40 psi
XXX	0.993 inch	0.406 inch	0.587 inch	0.321 inch	0.672 inch

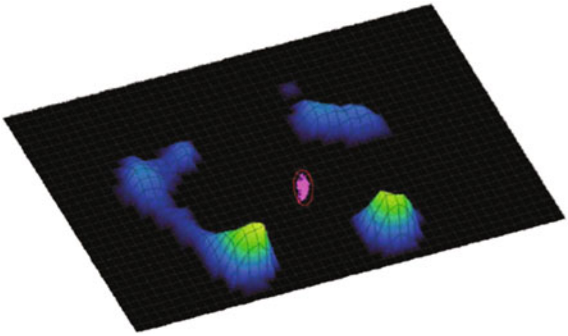


Fig. 6 Repartition of the foot pressure and the evolution of the center of pressure for the worker during balance

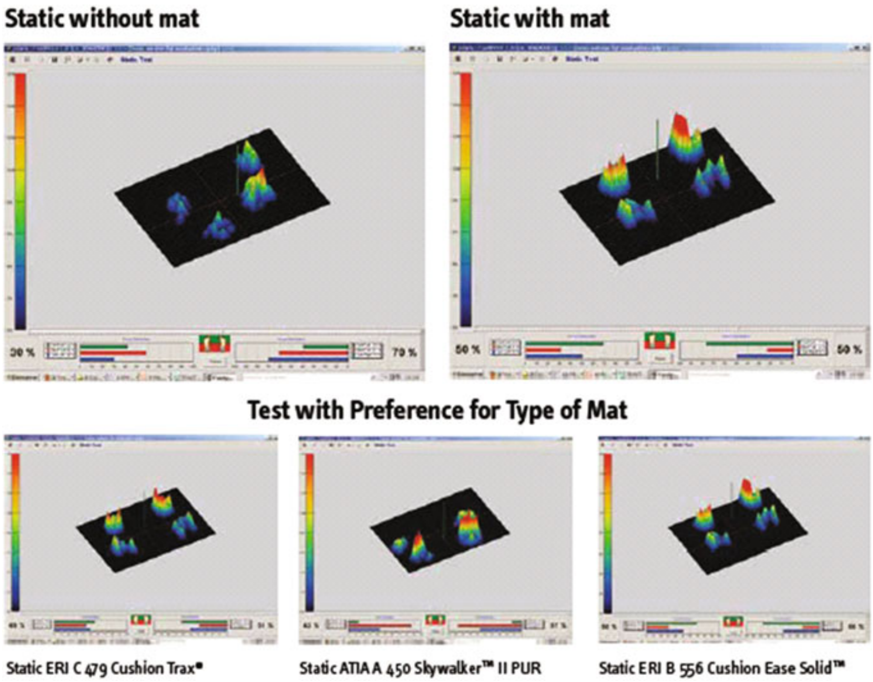


Fig. 7 Distribution using different mats for the better adaptation

As it is observed in this figure, the weight of the body is mainly on the right side when a distribution of foot pressure is 30 and 70 %. This imbalance is very harmful to the human body. The use of anti-fatigue mats enables correct balancing and a uniform distribution between the right and the left leg. The results showed the significant difference between the mats as well as with and without mats ($p < 0.05$). It should be noted that this balance is improved depending on the adaptation of the mat used. The Notrax® Cushion Ease™ mat tested at 'ERI B' showed best results for the test subjects. It seems that this mat is the best solution for the application at the company professionals tested. The Notrax® Cushion Trax® mat tested at 'ERI C' also showed interesting results but slightly less. We observe that in working situations where people make small movements constantly, the anti-fatigue mats that we tested show properties that give a muscular-skeletal comfort in upright working positions. This can be verified by the constancy of the force evolution curve during the movement.

7 Conclusions

The present study observed that in a static position the body of the subject moves in order to maintain balance. This first real life experiment 'variations in foot pressure' has made it possible to highlight the body's movements in a static position. To maintain an upright position, it is necessary to have a well-adapted postural balance to decrease pathologies and their consequences in the everyday work users. Recommendations should be provided to every user. The use of anti-fatigue mats contributed to highlighting of the benefits of new materials on the optimization of human mechanics. Retaking control of the muscle commands in the brain. Learning of a new gestural or postural model requires special attention and concentration during several weeks. Every gestural or postural system is controlled by the brain; this allows a compromise between quick execution and saving energy. When the system is out of balance, the quick reaction speed is maintained at the cost of energy spending (fatigue). That's the beginning of muscular-skeletal disorders and effects (pain, contractures, tendinitis etc). In a nutshell, to regain balance 'quick reaction/energy saving/effectiveness', it is necessary to become aware of the different foot pressures on the ground and the most proper muscle action (from feet to head). This can be done easily by changing the foot pressure on the floor: by forcing oneself from time to time to move the pressure to the front of the foot or towards the back of the feet; or from the inside to the outside of the foot or more to the right and after that, more to the left. Decreasing risk factors requires extensive knowledge on ergonomics and their applications in the work environment. Organizing training programs in firms and enterprises will help employees to fit in their environment in a healthy and safe way. This will lead to optimization of their performance.

Acknowledgments The authors would like to show our gratitude to Ms. Denisse Espino, Mr. Hugh Trenchard, Ms. Ellie Abdi for providing helpful insights.

References

1. Fourchet, F., Kelly, L., Horobeanu, C., Loepelt, H., Taiar, R., Millet, G.P.: Comparison of plantar pressure distribution in adolescent runners at low vs. high running velocity. Gait Posture **35**(4), 685–687 (2012)
2. Bourelle, S., Taiar, R., Berge, B., Gautheron, V., Cottalorda, J.: Diurnal changes in postural control in normal children: computerized static and dynamic assessments. Burn Trauma **2**(3), 130–135 (2014)
3. Regrain, E., Regnault, P., Kirtley, C., Shamshirband, S., Chays, A., Boyer, FC., Taiar, R.: Impact of multi-task on symptomatic patient affected by chronical vestibular disorders. Acta Bioeng. Biomech. (2016) (In press)
4. Te-Hsin, P., Kleiner, B.H.: New developments concerning the occupational safety and health act. J. Managerial Law **43**(1/2), 138–146 (2001)
5. Bongers, P.M., Kremer, A.M., Ter Laak, J.: Are psycosocial factors risk factors for symptoms and signs of the shoulder, elbow or hand/wrist? A review of the epidemiological literature. Am. J. Ind. Med. **41**(5), 315–342 (2002)
6. Taiar, R.: Ergonomics of the standing smart: increasing the comfort of standing workers. Adv. Hum. Fact./Ergon. SET **20**, 465–471 (2014)
7. Ferrari, F.J., Choukou, M.A., Gaillet, J.C., Taiar, R.: Comparaison de deux techniques de contention souple et leur influence sur l'équilibre postural. Neurophys. Clin. Neurophys. **1** (44), 148 (2014)
8. Praemer, A., Furner, S., Rice, D.P.: Musculoskeletal conditions in the United States. American Academy of Orthopaedic Surgeons, USA (1999)
9. Choukou, M.A., Ghouli, S., Quinart, H., Taiar, R.: Effects of wearing safety shoes with convex soles on gait cycle. Ann. Phys. Rehabil. Med. **56**(1), e26 (2013)
10. Choukou, M.A., Ghouli, S., Boyer, F.C., Taiar, R.: Effects of unstable footwear on stance pattern. J. Biosci. Med. **2**(3), 20–24 (2014)
11. Choukou, M.A., Jarlot, B., Arfaoui, A., Bourelle, S., Taiar, R.: Infrared thermograms: orthopedic diagnostics support. Ann. Phys. Rehabil. Med. **56**(supp 1), e285, (2013)
12. Perin, J., Agnesina, G., Taiar, R., Toshev, Y.: Analysis of the plantar foot pressure during walking: VFE position and VRI position. J. Biomech. **39**(supp 1), S552–S553 (2006)

Evaluating Usability of a Battery Swap Station for Electric Two Wheelers

Fei-Hui Huang

Abstract This study aims to elicit individuals' perceived quality of use for the battery swap station (BSS). An experiment was conducted with a sample of 92 participants who had experienced a battery swapping service, operation procedure, and filled out a usability evaluation questionnaire for eliciting their agreement of learnability, efficiency, memorability, errors, and satisfaction. The results showed that the average operation time was approximately 2.32 min. 33 errors had been made by the 92 participants. Also, most of participants agreed with the quality of use for the proposed BSS, especially for the learnability, efficiency, and satisfaction. However, memorability and errors were important issues to be improved for the proposed BSS and should be investigated further.

Keywords Electric two wheelers (E2Ws) · Battery swap station · Usability · Usability evaluation

1 Introduction

The world is in the face of an energy shortage, environmental pollution, and global warming [1]. Road transport is responsible for a significant and growing share of global anthropogenic emissions of CO_2. Using oil-derived fuels in internal combustion engines generates tailpipe emissions of pollutants such as PM_{10}, NO_x, and VOCs, which are harmful to human health. Road transport is almost entirely dependent on oil-derived fuels. Decreasing CO_2 emissions is viewed as an important policy around the world [2]. Recently, the development of electric vehicles (EVs) has become more popular due to their contribution of alleviating the global energy crisis and reducing emissions [3]. The development of EVs relies on

F.-H. Huang (✉)
Marketing and Distribution Management, Oriental Institute of Technology,
Pan-Chiao 22061, Taiwan, ROC
e-mail: Fn009@mail.oit.edu.tw

M. Soares et al. (eds.), *Advances in Ergonomics Modeling, Usability & Special Populations*, Advances in Intelligent Systems and Computing 486,
DOI 10.1007/978-3-319-41685-4_28

the charging patterns and available charging infrastructure, such as charging piles, charging station, and battery swap station (BSS) [4].

Taiwan has a population of 23 million, of which about 13.7 million are scooter users. Thus, one in every 1.67 people is a scooter commuter, which is the highest density in the world, and New Taipei City has the highest density in Taiwan. According to Taiwan's Environmental Protection Administration (EPA) report, emissions generated by scooters account for 330,000 tons of carbon monoxide and 90,000 tons of chemical compounds containing carbon hydroxide per year. The real-world operation of motorcycles/scooters results in a significant contribution of road transport CO and HC emissions, reaching 38 and 64 %, respectively, to the total emissions from road transportation [5]. In order to improve the air quality, the Taiwanese government is dedicated to promoting an eco-environmental protection policy. Increasing the penetration level of electric two wheelers (E2Ws) is one of the aims of the policy. The widespread adoption of E2W brings potential social and economic benefits, such as reducing the quantity of fossil fuels and greenhouse gas emissions, as well as environmental benefits. However, limitations on E2Ws batteries have meant that many people are unwilling to buy the related products. In spite of the incentives offered by Taiwan's government, the penetration level of E2W in the market is not encouraging. Only 29,942 e-scooters and 108,602 e-bikes were sold between 2009 and 2014.

A battery swapping model is proposed to overcome the battery limitations, including an expensive purchase price, short lifetime, limited driving range per charge, long charging time, and inconvenient charging, in order to improve the penetration of E2Ws in Taiwan. This model includes providing self-service battery swap stations (BSSs). The BSS, as one promising charging infrastructure, can provide great convenience to E2W customers without considering the all-electric range limit while the BSS is available. As of February 2014, there were 30 operational BSSs open to the public in New Taipei City, Taiwan. It is important to provide user-friendly BSS for E2W riders to enhance their willingness to accommodate related products and service. The purpose of this experimental study is to detect user external behaviors of operating the BSS, evaluate usability of BSS, and obtain the potential needs of E2W riders.

2 Literature Reviews

2.1 Battery Swapping System

A battery swapping model may provide a faster charging service than even the fastest recharging stations and lower the charging cost by charging depleted batteries overnight at a discounted electricity price. In this study, the battery swapping model separates the ownership of the battery and the E2W. Using a battery leasing service may also reduce the expense incurred by E2W owners. The model provides self-service BSSs, where an owner can ride to the nearest BSS and swap to a fully-charged battery within two minutes. BSS is one of the solutions to the limitations of the E2W battery [6–9]. The concept of an exchangeable battery service was first proposed as early as 1896 in order to overcome the limited operating range of electric cars and trucks [10]. BSS can also be regarded as energy-storage power stations, which can alleviate the variability and uncertainty of power output of renewable energy [11] and improve the management of a power grid [12]. BSS is usually connected to the megavolt-ampere scale substation [13] and requires high power during a day, which may lead to network overload. However, the charging load forecasting model for a BSS has not been included in [11–13], and the BSS is not simply a storage power plant which should also satisfy the battery swapping demand of E2Ws [11, 12].

BSS can offer great convenience for travel range that is longer than the driving range per charge of the vehicle. However, the BSS is not widely used due to the lack of standardization of batteries and interfaces. In this study, the battery swapping system comprises four industries: battery swapping system operators, E2W battery manufacturers, E2W manufacturers, and E2W retailers. In order to effectively integrate the industries and adopt the battery swapping system, battery certification specifications for E2Ws have been drafted to formulate a size standard for 48 V/10Ah–15Ah lithium-ion batteries, interchangeable interface standards to link batteries and vehicles, and a Taiwan E-scooter Standard (TES) for performance and safety. The draft was announced by Taiwan's EPA on December 9, 2013, to ensure the consistency of battery and vehicle quality. Here, E2Ws include electric scooters (e-scooter), electric bicycles (e-bike), and electric-assisted bicycles. According to E2W traffic laws, e-scooters are limited to 1000 W output, and cannot travel faster than 45 km/h on motor power alone on level ground. A driver's license and helmet are required to ride an e-scooter. E-bikes and electric-assisted bicycles cannot travel faster than 25 km/h. There is no lower age limit, so anyone can legally ride an e-bike or electric-assisted bicycles on roads. Furthermore, based on the swapping service availability, the construction cost of the system is the primary problem for investors.

2.2 Usability

The battery swapping system services require the support of the above-mentioned four industries. This highlights the importance of industrial integration and user acceptance for the battery swapping system. Moreover, system acceptability is the major issue addressed in this study. Nielsen's system acceptability model may provide an overview of the issues that influence the service acceptance of a system. Nielsen [14] defines acceptability as "whether the system is good enough to satisfy all the needs and requirements of the user." System acceptability is the goal designers should aim for and can be achieved by meeting the social and practical acceptability objectives of the system. Hence, the Nielsen system acceptability model is a combination of social acceptability and practical acceptability. With regard to practical acceptability, it is a combination of the characteristics of the system, including its usefulness, cost/price, compatibility, reliability.

Usefulness has been identified as a key objective of practical acceptability. Usefulness refers to how well a system achieves a desired goal, and is divided into two subcategories: utility and usability [15]. Utility is the question of whether that functionality in principle can do what is needed; usability is the question of how well users can use the functionality of a system [16]. The two concepts of usability and utility are highly interrelated. A usable user interface may contribute to a service being perceived as having the utility to provide appropriate functionality. Conversely, if a service has the utility to provide appropriate functionality, but can only be used or consumed via a badly designed user interface, users may avoid using the product or service.

With regard to the definition of usability, Bevan et al. [17] focus on how usability should be measured, with a particular emphasis on either ease of use or acceptability. The usability of a product is affected not only by the features of the product itself, but also by the characteristics of the users, the tasks they are carrying out, and the technical, organizational and physical environment in which the product is used [14]. Then, Nielsen [15] further defines a usable system as a quality attribute that assesses how easy user interfaces are to use, and outlines five usability attributes: learnability, efficiency, memorability, error recovery/few errors, and satisfaction. The definition of learnability is that "how easy is it for users to accomplish basic tasks the first time they encounter the design". The definition of efficiency is that "once users have learned the design, how quickly can they perform tasks". The definition of memorability is that "when users return to the design after a period of not using it, how easily can they reestablish proficiency". The definition of errors is that "how many errors do users make, how severe are these errors, and how easily can they recover from the errors". The definition of satisfaction is that "how pleasant is it to use the design". The principles of usability are concerned with the five usability attributes, and are connected to the usefulness of a product. The International Organization of Standards (ISO) [18] defines usability as the extent to which a product can be used by specified users to achieve specified goals with effectiveness, efficiency, and satisfaction in a specified context of use. Usability plays a role in each stage of the design process. Also, the only way to a high-quality user experience is to start usability evaluation early in the design process and to keep evaluation every step of the way. The outcome of a usability study is generally expected to be some recommendations on how to improve the product and how to make it easier and more enjoyable to use.

3 Methods

The BSS is self-service only. It is important to provide user-friendly BSS for E2W riders. This study forms investigation into user-based usability evaluation methods (UEM) based on experimental and survey studies for evaluating usability of the BSSs. The materials of the study are described as below:

1. Taiwan Electric Scooter Development Association (TESDA) provided 2 e-scooters for this study. It allowed experimental participants to have a real battery swapping experience at BSS. Each e-scooter with 2 batteries.
2. TESDA provided 1 BSS. It was located at Oriental Institute of Technology campus during the experimental period. The location of BSS is near the hospital, market, and MRT (Mass Rapid Transit) station. It was expected to recruit experimental participants easily and provide them to have a real battery swapping experience.
3. An experimental record form was developed to record each participant's operation time and errors for researchers. The operation time is that the total time participant spent in action was recorded from the start-up of scan ID card to the end of the second battery on the track removed to the E2W.
4. End-of-experiment subjective rating for BSS usability evaluation contained the following six sections—(1) personal information: three items designed to collect socio-demographic data on age (20–24, 25–34, 35–44, 45–54, 55–64, 65–74, and ≥ 75), sex (male and female), education (elementary, junior high, high school (senior), college, master's degree, and other), and occupation (student, industrial, commercial, service industry, teacher, and other); (2) learnability: five items designed to collect categorical quantitative data concerning interface, operational complexity, operation procedure, helpful information, and independently complete, assessed using a 5-point Likert scale ranging from *strongly agree* to *strongly disagree*; (3) efficiency: five items designed to collect categorical quantitative data concerning ID card sensor, confirm button, the use of the battery cover, remove batteries, and operational efficiency, assessed using a 5-point Likert scale ranging from *strongly agree* to *strongly disagree*; (4) memorability: three items designed to collect categorical quantitative data concerning assistance needs, needs of text information guide on the BSS interface, and operational efficiency, assessed using a 5-point Likert scale ranging from *strongly agree* to *strongly disagree*; (5) error recovery: five items designed to collect categorical quantitative data concerning the use of ID card, withdraw the track in a short term, re-operation, improper operation, and the need of voice guidance, assessed using a 5-point Likert scale ranging from *strongly agree* to *strongly disagree*; (6) satisfaction: four items designed to collect categorical quantitative data concerning BSS desing, operation procedure, battery weight, and system information, assessed using a 5-point Likert scale ranging from *strongly agree* to *strongly disagree*.
5. All of the participants have to complete the operation procedure of swapping 2 batteries for an e-scooter, after researcher introduced the experimental procedure

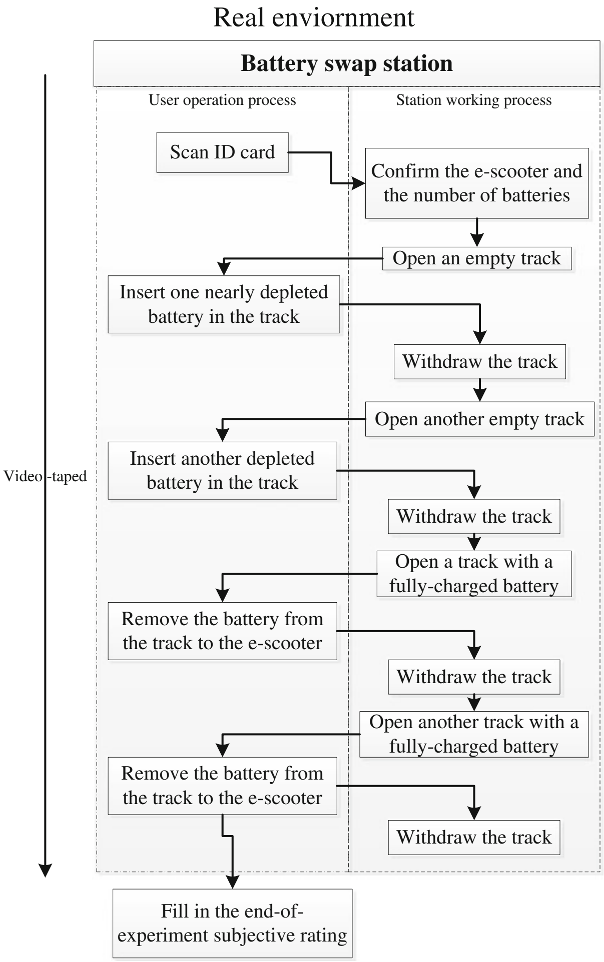


Fig. 1 Experimental procedure

which is shown in Fig. 1. During the term of swapping batteries for each participants, researcher record each participant's operation time and errors and video-taped. The key action to start swapping battery is to sense e-scooter's ID card on BSS. After the system conform the e-scooter's information, BSS may open an empty track for participant to insert battery in the track. After make user 2 batteries has been inserted in the BSS successfully, BSS may open a track with a fully-charged battery for participant to remove it from the track to the e-scooter. After 2 nearly depleted batteries has been exchange to the 2 fully-charged batteries, participant has to fill out the usability evaluation questionnaire.

The study was conducted over a month period on October 2014.

4 Results

Of 95 participants, 3 end-of-experiment subjective ratings involved material data omission, and the effective response rate was 96 %. For the 92 participants who completed the experiment and end-of-experiment subjective ratings, summarized data are shown in Table 1.

4.1 Descriptive Statistics

The average operation time to complete swapping batteries for the experimental participants was 138.96 s ($\sigma = 38.24$), amongst inserted 2 nearly depleted batteries in the track ($\bar{X} = 48.30$ s, $\sigma = 25.24$) and removed 2 fully-charged batteries from the track to the e-scooter ($\bar{X} = 42.59$ s, $\sigma = 11.10$). 33 errors were made by the participants, including the participants standard in the battery operation zone and caused BSS stopped working (18 times), putted battery on the BSS in the wrong direction or position (9 times), and could not find where to scan the ID card (6 times). During the experimental period, 4 times abnormal operation of the BSS were happened. With regard to usability evaluation, the most agreed factor of usability for participants was efficiency ($\bar{X} = 4.31$, $\sigma = .73$), followed by learnability ($\bar{X} = 3.91$, $\sigma = .53$), satisfaction ($\bar{X} = 3.9$, $\sigma = .77$), and memorability ($\bar{X} = 3.49$, $\sigma = .53$). Most of participants were not agreed that the BSS may support them to avoid errors or to recover from the errors ($\bar{X} = 2.50$, $\sigma = .58$).

Table 1 Demographic information of the participants (N = 92)

Items		Frequency (n) and sequence					
		1	2	3	4	5	6
Gender	Item Total %	Male 65 (70.7)	Female 27 (29.3)				
Age	Item Total %	20–24 73 (79.3)	25–34 12 (13.0)	35–44 4 (4.3)	45–54 2 (1.1)	55–64 1 (2.2)	
Education	Item Total %	College 72 (78.3)	Senior 10 (10.9)	≥ Master 8 (8.7)	Junior 2 (2.2)		
Occupation	Item Total %	Student 67 (72.8)	Industrial 6 (6.5)	Service industry 5 (5.4)	Commercial 5 (5.4)	Other 5 (5.4)	Teacher 2 (2.2)

4.2 t Test

The dependent samples *t*-test results indicated that operation time differed significantly (p = .032) between inserted 2 nearly depleted battery in the track (=48.30 s, σ = 25.24) and removed 2 fully-charged batteries from the track to the e-scooter ($\bar{X}$ = 42.59 s, σ = 1.55).

The *t* -test results indicated that the needs of text information guide on the BSS interface differed significantly ($t = 3.05$, $p = .004$) between men ($\bar{X}$ = 3.75, σ = 1.05) and women ($\bar{X}$ = 2.93, σ = 1.24).

4.3 Correlation Analysis

The correlation analysis results showed that efficiency was positively correlated with learnability ($r = .529$, $p < .01$), memorability ($r = .294$, $p < .01$), and satisfaction ($r = .496$, $p < .01$). Efficiency was negatively correlated with errors ($r = -.359$, $p < .01$). With regard to the errors, it were negatively correlated with learnability ($r = -.266$, $p < .05$), efficiency ($r = -.359$, $p < .01$), and satisfaction ($r = -.282$, $p < .01$), and was positively correlated with memorability ($r = .224$, $p < .05$). With regard to the momorability, it were positively correlated with learnability ($r = .372$, $p < .01$), efficiency ($r = .294$, $p < .01$), and errors ($r = .224$, $p < .05$). With regard to the learnability, it were positively correlated with efficiency ($r = .529$, $p < .01$), momorability ($r = .372$, $p < .01$), and satisfaction ($r = .589$, $p < .01$), and was negative correlated with errors ($r = -.266$, $p < .05$). With regard to the satisfaction, it were positively correlated with learnability ($r = .589$, $p < .01$) and efficiency ($r = .496$, $p < .01$), and were negatively correlated with errors ($r = -.282$, $p < .01$).

5 Discussion

The average operation time for e-scooter riders to accomplish swapping batteries by using the proposed BSS was approximately 2.32 min. In addition, the average operation time for users to accomplish inserting 2 nearly deleted batteries in the track was approximately 48.3 s. The average operation time for users to accomplish remove 2 batteries from the track to the e-scooter was approximately 42.59 s. It also showed a significant learning effect for using the self-service BSS. However, several usability problems had been found and need to be improved in the near future.

The important problems caused users making errors were improper BSS designs, including sensing zone, battery track, and ID sensor zone. With regard to sensing zone design, it was designed to avoid pinched user when the track is withdrew.

However, the designed distance between BSS and user is too long distance. It was limited by the battery size and the track design. It also leaded that BSS users have to go back 1or 2 steps after insert or remove battery for the station continuing operation. With regard to battery track design, 9 participants insert the battery with wrong direction. Furthermore, the battery track design is limited by battery size and design. Finally, results showed that 6 participants could not find where to sense the ID card. Although the errors participants made were easily to recover, and the error rate is not high (35.9 %), the results of the usability evaluation displayed that the only one factor participants not agreed was errors ($\bar{X}$ = 2.50, σ = .58). In addition, 4 times malfunctions of track open or withdraw happened during the experimental period. These may highlight the important of battery design, remove and insert battery design, and BSS reliability.

Most of participants agreed with the BSS design may meet their needs of efficiency, learnability, and satisfaction. Results of usability evaluation also showed users need more memory resources to accomplish swapping batteries caused more errors been made. Moreover, male needed more text information guide on BSS then female did. It showed that users require real-time operating instructions to assist them complete all tasks.

6 Conclusion

In this study, an experiment and a survey of usability evaluation were conducted to find participant's operation time and errors of using the proposed BSS and elicit their feedback of quality of using BSS including learnability, efficiency, memorability, error recovery/few errors, and satisfaction. The results of current study indicate that users may complete swapping batteries in approximately 2.32 min by using the proposed BSS. The BSS may provide a nice learning effect. Most of participants agreed with quality of using BSS, including learnability, efficiency, and satisfaction. However, memorability and errors need to be improved. In order to increase the quality of use for the proposed BSS, memorability, errors, and re-design battery and BSS should be investigated further.

Acknowledgments The author would like to express her gratitude to Taiwan Electric Scooter Development Association for setting up exhibitions for this study and Environmental Protection Administration of Taiwan for the funding under the grant number EPA-102-FA13-03A291.

References

1. Lopes, J.A.P., Soares, F.J., Almeida, P.M.R.: Integration of electric vehicles in the electric power system. Proc. IEEE **99**(1), 168–183 (2011)
2. Lund, H., Clark, W.W.: Sustainable energy and transportation systems introduction and overview. Util. Policy **16**, 59–62 (2008)

3. Parks, K., Denholm, P., Markel, T.: Costs and emissions associated with plug-in hybrid electric vehicle charging in the Xcel energy Colorado service territory. Technical Report NREL/TP-640-41410. National Renewable Energy Laboratory, Golden, CO, USA (May 2007)
4. Su, W., Eichi, H., Zeng, W., Chow, M.Y.: A survey on the electrification of transportation in a smart grid environment. IEEE Trans. Ind. Inf. **8**(1), 1–10 (2012)
5. Tsai, J.H., Hsu, Y.C., Weng, H.C., Lin, W.Y., Jeng, F.T.: Air-pollution emission factors from new and in-use motorcycles. Atmos. Environ. **34**, 4747–4754 (2000)
6. Li, J.Q.: Transit bus scheduling with limited energy. Transport. Sci. **48**(4), 521–539 (2014). doi:10.1287/trsc.2013.0468
7. Liu, J.: Electric vehicle charging infrastructure assignment and power grid impacts assessment in Beijing. Energy Policy **51**, 544–557 (2012)
8. Worley, O., Klabjan, D.: Optimization of battery charging and purchasing at electric vehicle battery swap stations Chicago. In: IL IEEE Vehicle Power and Propulsion Conference (VPPC), vol. 6–9, pp. 1–4 (Sept 2011)
9. Lombardi, P., Heuer, M., Styczynski, Z.: Battery switch station as storage system in an autonomous power system: optimization issue. In: Minneapolis, MN IEEE Power and Energy Society General Meeting, vol. 25–29, pp. 1–6 (July 2010)
10. Kirsch, D.A.: The Electric Vehicle and the Burden of History, pp. 153–162. Rutgers University Press, New Brunswick (2000)
11. Takagi, M., Iwafune, Y., Yamamoto, H., Yamaji, K., Okano, K., Hiwatari, R., Ikeya, T.: Economic value of PV energy storage using batteries of battery switch stations. IEEE Trans. Sust. Energy. **4**(1), 164–173 (2013)
12. Lombardi, P., Heuer, M., Styczynski, Z.: Battery switch station as storage system in an autonomous power system: optimization issue. In: Proceedings of IEEE Power Energy Society General Meeting, pp. 1—6 (2010)
13. Wang, C., Yang, J., Liu, N., Mao, Y.: Study on sitting and sizing of battery-switch station. In: Proceedings of 4th International Conference on Electric Utility Deregulation and Restructuring and Power Technologies, pp. 657—662 (2011)
14. Thomas, C., Bevan, N.: Usability context analysis: a practical guide. Teddington, UK (1996)
15. Nielsen, J.: Usability Engineering. Academic Press, Cambridge (1993)
16. Grudin, J.: Utility and usability: research issues and development contexts. Interact. Comput. **4** (2), 209–217 (1992)
17. Bevan, N., Kirakowski, J., Maissel, J.: Proceedings of the 4th International Conference on HCI, Stuttgart. http://www.nigelbevan.com/papers/whatis92.pdf (1991)
18. ISO 9241-11: International standard first edition. Ergonomic requirements for office work with visual display terminals (VDTs). Part 11: Guidance on usability. http://www.idemployee.id.tue.nl/g.w.m.rauterberg/lecturenotes/ISO9241part11.pdf (1998)

System Acceptability Evaluation of Battery Swapping System for Electric Two Wheelers

Fei-Hui Huang

Abstract In order to improve penetration in Taiwan's electric two wheeler (E2W) market to decrease emissions of pollutants generated by scooters, a battery swapping model is proposed to overcome battery limitations. This study aims to understand individuals' willingness to accept the battery swapping system. Event marketing was used to recruit target audiences, resulting in a sample of 1422 riders who had experienced a battery swapping service and filled out a post-experience questionnaire for eliciting their traffic demands, the system acceptability, and purchase intention. The results showed that approximately 90 % of riders adopted such system, but only 6.2 % were willing to purchase an e-scooter. Thus, there is a high degree of system adoption, but having E2Ws adopted in the short term is a challenge. Riders identified a number of problems with the self-service battery swap stations (BSS). These problems are discussed and related recommendations of resolving such problems are addressed.

Keywords Electric two wheelers (E2Ws) · E-scooter · Battery swapping model · System acceptability · Experiential marketing · Exhibitions

1 Introduction

Taiwan has a population of 23 million, of which about 13.7 million are scooter users. Thus, one in every 1.67 people is a scooter commuter, which is the highest density in the world, and New Taipei City has the highest density in Taiwan. According to Taiwan's Environmental Protection Administration (EPA) report, emissions generated by scooters account for 330,000 tons of carbon monoxide and 90,000 tons of chemical compounds containing carbon hydroxide per year. The real-world operation of motorcycles/scooters results in a significant contribution of

F.-H. Huang (✉)
Marketing and Distribution Management, Oriental Institute of Technology, Pan-Chiao 22061, Taiwan, ROC
e-mail: Fn009@mail.oit.edu.tw

M. Soares et al. (eds.), *Advances in Ergonomics Modeling, Usability & Special Populations*, Advances in Intelligent Systems and Computing 486,
DOI 10.1007/978-3-319-41685-4_29

road transport CO and HC emissions, reaching 38 and 64 %, respectively, to the total emissions from road transportation [1].

In order to improve the air quality, the Taiwanese government is dedicated to promoting an eco-environmental protection policy. Increasing the penetration level of electric two wheelers (E2Ws) is one of the aims of the policy. The widespread adoption of E2W brings potential social and economic benefits, such as reducing the quantity of fossil fuels and greenhouse gas emissions, as well as environmental benefits. However, limitations on E2Ws batteries, including an expensive purchase price, short lifetime, limited driving range per charge, long charging time, and inconvenient charging, have meant that many people are unwilling to buy the related products. In spite of the incentives offered by Taiwan's government, the penetration level of E2W in the market is not encouraging. Only 29,942 e-scooters and 108,602 e-bikes were sold between 2009 and 2014.

A battery swapping model is proposed to overcome the battery charging and driving range limitations in order to improve the penetration of E2Ws in Taiwan. The purpose of this study is to understand individuals' willingness to accept a battery swapping system, and whether providing such a system may potentially enhance their willingness to change their behavior to accommodate e-scooters.

2 Literature Reviews

2.1 Battery Swapping System

A battery swapping model may provide a faster charging service than even the fastest recharging stations and lower the charging cost by charging depleted batteries overnight at a discounted electricity price. In this study, the battery swapping model separates the ownership of the battery and the E2W. Using a battery leasing service may also reduce the expense incurred by E2W owners.

The model provides self-service BSSs, where an owner can ride to the nearest BSS and swap to a fully-charged battery within two minutes. The concept of an exchangeable battery service was first proposed as early as 1896 in order to overcome the limited operating range of electric cars and trucks [2]. In addition, BSS is one of the solutions to the limitations of the E2W battery [3–6].

The battery swapping system comprises four industries: battery swapping system operators, E2W battery manufacturers, E2W manufacturers, and E2W retailers. In order to effectively integrate the industries and adopt the battery swapping system, battery certification specifications for E2Ws have been drafted to formulate a size standard for 48 V/10Ah–15Ah lithium-ion batteries, interchangeable interface standards to link batteries and vehicles, and a Taiwan E-scooter Standard (TES) for performance and safety. The draft was announced by Taiwan's EPA on December 9, 2013, to ensure the consistency of battery and vehicle quality.

Here, E2Ws include electric scooters (e-scooter), electric bicycles (e-bike), and electric-assisted bicycles. According to E2W traffic laws, e-scooters are limited to 1000 W output, and cannot travel faster than 45 km/h on motor power alone on level ground. A driver's license and helmet are required to ride an e-scooter. E-bikes and electric-assisted bicycles cannot travel faster than 25 km/h. There is no lower age limit, so anyone can legally ride an e-bike or electric-assisted bicycles on roads. Furthermore, based on the swapping service availability, the construction cost of the system is the primary problem for investors. Because the construction of BSSs and their infrastructure is expensive, there are 30 operational BSSs open to the public in limited locations in New Taipei City, Taiwan. These have been set in seven of New Taipei City's 29 districts. The average distance between each station is about 3.5 km.

2.2 System Acceptability

The battery swapping system services require the support of the above-mentioned four industries. This highlights the importance of industrial integration and user acceptance for the battery swapping system. Moreover, system acceptability is the major issue addressed in this study.

Nielsen's system acceptability model may provide an overview of the issues that influence the service acceptance of a system. Nielsen [7] defines acceptability as "whether the system is good enough to satisfy all the needs and requirements of the user." System acceptability is the goal designers should aim for and can be achieved by meeting the social and practical acceptability objectives of the system. Hence, the Nielsen system acceptability model is a combination of social acceptability and practical acceptability.

Social acceptability recognizes the broader social issues that affect system users [7]. The concept of social acceptability is needed to understand the social context of users, why the activity is performed in a certain way, and how tools can be adapted or designed to support it. Social aspects may influence the adoption [8] and manner of using the product and service. Individuals evaluate social acceptability when their motivation to use technology competes with social restrictions. Individuals make decisions on the social acceptability of their actions by gathering information about their current surroundings and using their existing knowledge [9].

Practical acceptability is a combination of the characteristics of the system, including its usefulness, cost/price, compatibility, reliability. Usefulness has been identified as a key objective of practical acceptability. Usefulness refers to how well a system achieves a desired goal, and is divided into two subcategories: utility and usability [10]. Here, utility refers to whether appropriate functionality is at hand, and usability refers to how well users can apply that functionality. With regard to the definition of usability, Bevan et al. [11] focus on how usability should be measured, with a particular emphasis on either ease of use or acceptability. Then, Nielsen [7] further defines a usable system as a quality attribute that assesses how easy user interfaces are to use, and outlines five usability attributes: learnability, efficiency, memorability, error recovery/few errors, and satisfaction. The International Organization of Standards (ISO) [12] defines usability as the extent to which a product can be used by specified users to achieve specified goals with effectiveness, efficiency, and satisfaction in a specified context of use. The two concepts of usability and utility are highly interrelated. A usable user interface may contribute to a service being perceived as having the utility to provide appropriate functionality. Conversely, if a service has the utility to provide appropriate functionality, but can only be used or consumed via a badly designed user interface, users may avoid using the product or service.

2.3 Event and Experiential Marketing

Event marketing is defined as the marketing discipline focused on face-to-face interaction via live events, trade shows, and corporate meetings, among other event types. An event is a live occurrence with an audience. If an audience exists, then a message or experience is shared, transmitted, and generated. In fact, very few events are not able to be used for marketing, because event marketing is a communication tool, and has the potential to communicate with a target audience to market a product/service. Furthermore, marketing events have the potential to create an extraordinary experience for the consumer, develop relationships with customers, link the brand to good causes, and build, change, and reinforce a brand image through the association with the event. Marketing events include incentive/reward events, product launches, open days, conferences, product sampling, publicity events, created events, road shows, press conferences, corporate entertainment, exhibitions, product visitor attractions, charity fundraisers, and competitions/contests [13].

Experiential marketing is the process of identifying and satisfying customer needs and aspirations profitably, engaging with them through two-way communications that bring brand personalities to life, and adding value to the target audience [14]. Experiential marketing was derived from the concept of experience economy, as proposed by Pine and Gilmore [15]. Experience, as defined within the realms of management, involves a personal occurrence with emotional significance created by an interaction with product- or brand-related stimuli [16]. Moreover, consumer behavior has an experiential dimension. Consumer behavioral facets relate to the multi-sensory, fantasy, and emotive aspects of product use [17]. An experience occurs "when a company intentionally uses services as the stage, and goods as props, to engage individual customers in a way that creates a memorable event" [15]. In order words, experiential marketing can deliver sensory, emotional, cognitive, behavioral, and relational values that replace customers' functional values, and to which social- and informational-based values can be added [18]. Furthermore, the result of experiential marketing must be "something extremely significant and unforgettable for the consumer immersed into the experience" [19].

A battery swapping system is an innovative service to provide a convenient charging service to E2W riders. The purpose of this study is to understand individuals' acceptance of a self-service BSS. In order to recruit target audiences, event marketing and experiential marketing are used.

3 Methods

The Taiwan Electric Scooter Development Association (TESDA) set up nine exhibitions to promote and market E2W and BSS to the public and to recruit target audiences for this study. The exhibitions were held at various destinations in New Taipei City in the Xinzhuang District, Luzhou District, Banqiao District, and Sanchong District.

Here, an exhibit marketing plan, including direct mail, advertising, the Internet, and various products and services, was used to attract potential buyers' attention. Each exhibition gathered 30+ participants, including 10 E2W retailers and 1 battery swapping system operator. In each exhibition, one BSS and approximately 85 plug-in E2Ws and 15 e-scooters that require the BSS service were on display. Individuals were allowed to ride on the 15 e-scooters and to swap the battery at the BSS. In addition, each exhibition attendee was introduced and encouraged to take a trial ride on an e-scooter and swap the battery at the BSS. Individuals could sign up for an immersive experience for a maximum trial period of three hours. These experiences gave trial riders an opportunity to understand, adapt, and overcome any battery charging and driving range limitations.

The paper-and-pen questionnaire for the post-experience feedback contained the following five sections—(1) personal information: five items designed to collect socio-demographic data on age (<20, 20–29, 30–39, 40–49, 50–59, 60–69, and ≥ 70), sex (male and female), education (elementary, junior high, high school (senior), college, master's degree, and other), name, and phone number; (2) exhibit marketing: one item designed to collect categorical data about exhibition information received from direct mail, the exhibition, the Internet, advertising, friends, and others; (3) individual traffic demands: two items designed to collect categorical data on transportation usage (scooter, bike, walk, car, public transportation, and other) and daily commuting distance (<10, 10–19, 20–29, 30–39, and ≥ 40 km); (4) system acceptability evaluation: two items designed to collect categorical data on practical acceptability—"Which factors made you unsatisfied with the battery swapping system and why?" (utility, usability, environment, and price)—and social acceptability—"Is the system convenient?" (yes or no). Here, social acceptability is identified as the convenience factors that influence users' willingness to use the battery swapping system, but does not provide insight into what those factors are or how they might influence riders' opinions; (5) purchase intention: three items designed to collect categorical data on respondent's willingness to own an e-scooter (yes, maybe, and no), reasons for not wanting to own an e-scooter (speed, appearance, performance, price, driving range per charge, BSS services, and other), and e-scooter usage (sports and leisure, shopping, picking up a child from school, commuting, long-distance travel, and other). Of the 13 items, multiple answers are allowed in five items: exhibition information, transportation usage, reasons for not buying an E2W, practical acceptability, and E2W usage. After returning the e-scooters, each trial rider filled out a questionnaire and obtained a bag of polished rice as a reward.

The study was conducted over a five-month period between June and October 2014. During the period, nine exhibitions were held at different places and times. The first exhibition was open for one day, the following seven were open for two days each, and the final one was open for 15 days.

4 Results

Exhibitions were attended by 11,000+ citizens, and 1422 riders tested e-scooter products and the BSS service. Table 1 shows the demographic information of the 1422 riders who completed the surveys. Results showed that approximately 58.4 % of participants (830) were man and 41.6 % (592) were woman. The age ranges were <20 (7.5 %), 20–29 (21.8 %), 30–39 (20.5 %), 40–49 (18.4 %), 50–59 (19.3 %), 60–69 (9.8 %), and ≥ 70 (2.8 %). The educational ranges were elementary (6.0 %), junior high school (9.1 %), senior high school (22.7 %), college (53.3 %), $\geq$ Master (6.6 %), and other (2.3 %).

4.1 Descriptive Statistics

Most of the trial riders received exhibition information from the exhibition (62.4 %) by, for example, passing by the current or past exhibition, followed by advertising (14.7 %), friends (13.8 %), and other (6.8 %). The results showed that approximately 62.7 % of trial riders were using high air-polluting road vehicles as their major means of transport, including scooters (53.8 %), buses (6.2 %), and cars (2.7 %). Approximately 71.5 % of trial riders commuted less than 20 km (one way) per day. After riding the e-scooter, there were 1656 unsatisfied checks for practical acceptability from the 1422 trial riders, including usability (38.3 %), utility (24.0 %), environment (23.3 %), and price (14.3 %). However, approximately 97.1 % riders were still willing to use the battery swapping system, with only 2.9 % of riders not finding the system convenient. With regard to the purchasing intention, approximately 6.3 % riders were willing to own the e-scooter and 83.8 % were willing to consider purchasing the e-scooter. Approximately 97.9 % would ride the e-scooter as means of transport for short-distance travel (e.g., shopping, picking up children from school, commuting to work, and sports). The remaining 10 % of riders were willing to trial ride the e-scooter, but not to purchase it. The major reason for the latter result was the speed of the e-scooter, followed by the BSS service, driving range per charge, performance, and price.

4.2 Chi-Square Test

The chi-square test results indicate that trial riders' one-way daily commuting distances differed significantly according to educational level and sex. The results showed significant differences in the purchase intentions of e-scooter according to age. Trial riders who had received a junior high education displayed a higher percentage of one-way daily commuting under 10 km (4.5 %; AR = 2.3) relative to those with a master's degree (1.6 %; AR = −3.2). In contrast, trial riders who had received a master's degree displayed a higher percentage of one-way daily commuting of 30–39 km (0.8 %; AR = 2.3) relative to those with a senior high education (0.8 %; AR = −2.1). They also showed a higher percentage of daily commuting ≥ 40 km (0.9 %; AR = 3) relative to those with an elementary education (0.1 %; AR = −1.6). Women exhibited a higher percentage of daily commuting under 10 km (21.8 %; AR = 7.8) relative to men (18.5 %; AR = −7.8). In contrast, men exhibited a higher percentage of daily commuting ≥ 10 km relative to women. In addition, trial riders aged 30–39 years displayed a higher intention to purchase an e-scooter with the BSS (1.9 %; AR = 2.5) relative to those aged 20–29 years (0.6 %; AR = −3).

4.3 Cross-Tabulation

With regard to e-scooter usage of men, the greatest need in daily life was shopping nearby, followed by sports and leisure, picking up children from school, and commuting to work. For women, the greatest need was shopping nearby, followed by picking up children from school, commuting to work, and sports and leisure. Men most often used scooters, followed by cars, buses, bikes, and walking. Women most often used scooters, followed by buses, bikes, walking, and cars. Finally, with regard to the E2W usage of different age ranges, trial riders aged >29 would ride e-scooters to shop nearby, for sports and leisure, and to stroll nearby; trial riders aged ≥ 30 would ride e-scooters to shop nearby, pick up children, and commute to work.

5 Discussion

The event marketing successfully reached 11,000+ individuals who attended the exhibitions, and the experiential marketing created compelling reasons for results in 1422 riders who experienced the e-scooter products and the BSS service. The results showed that approximately 76.2 % of the trial riders received the event information from a variety of advertisements, and 13.8 % received information from friends and relatives. This means that exhibitions successfully created news and opportunities for free trial rides for potential customers, and assisted them to clearly see the benefits of what the exhibition was showing and promoting. After testing the e-scooter product and BSS service, trial riders talked about the exhibitions or free trial experiences among their friends, which created word-of-mouth opportunities. Of the 1422 riders, the major transportation usage was a scooter (53.8 %), followed by a car (13.4 %), bus (13.3 %), bike (9.5 %), and walking (8.4 %). After they were educated about the battery swapping system, BSS, E2W, the benefits and potential drawbacks, and had experienced the system for a maximum trial period of three hours, 90 % of the trial riders were willing to adopt the system. Of these, 6.2 % were willing to purchase an e-scooter as well. Then, 83.8 % wanted time to consider whether to purchase an e-scooter. The remaining 10 % of the trial riders preferred to keep their original modes of transport and not to consider buying an e-scooter.

5.1 Purchase Intention

Only 88 trial riders were willing to buy an e-scooter. During the study period, most of the e-scooter buyers needed to buy a scooter or bike. Of the 1192 trial riders who were willing to consider buying e-scooter, approximately 923 (53.3 %) were scooter riders. In Taiwan, the density of scooter owners, one in every 1.67 people, is high. Because scooters are a relatively economical way to commute, the majority of scooter-based commuters are from middle- and low-income families. Even though an e-scooter is half the price of a regular scooter, most people prefer to ride their original scooter, and not to replace it with a new e-scooter. Then, 228 trial riders (13.2 %) were car owners, and may be willing to purchase an e-scooter if they found them practical and convenient. Of the 1422 trial riders, 142 (10 %) were not willing to purchase an e-scooter and the BSS service. The results indicated that E2W speed was the major reason 76 riders (23.8 %) were not willing to become an e-scooter owner. The maximum speed of e-scooter is 45 km/h. This is fast enough to meet the speed limit on the main roads of Taiwan (40–50 km/h). Of 76 trial riders, 71 were scooter commuters. Because the maximum speed of a regular scooter is 110–130 km/h, they may be used to ignoring the speed limit and driving at far higher speeds. Then, 70 riders (21.8 %) were not willing to buy e-scooter because they were not satisfied with the BSS service. Because the battery swapping model is in the initial planning phase and is expensive to implement, only 30 BSSs have been established, and are set in seven of New Taipei City's 29 districts. This leads to a drawback of low BSS universality and density. In order to increase individuals' purchase intentions, two wheeler speed limits on the roads need clear norms and the density of BSSs should be increased.

5.2 Potential Customers and Their Needs

Individual differences in the daily commuting distance and the purchase intentions of trial riders were observed. The average one-way daily commuting distance differed according to educational levels and sex. The results showed that men displayed a higher percentage of daily commuting of ≥ 10 km relative to women. Moreover, the most used means of transport by men was a scooter, followed by a car, bus, and bike. Compared with women, their most used means of transport was a scooter, followed by a bus, bike, and walking. In addition, trial riders with a higher level of education (e.g., a master's degree), displayed a higher percentage of daily commuting of ≥ 30 km relative to other rider groups. In other words, riders who were women or who had a lower level of education tended to travel a shorter distance in their daily lives. Then, purchasing intentions differed slightly according to age. The results showed that trial riders aged 30–39 years exhibited a slightly higher intention to purchase an e-scooter relative to other rider groups. In summary, women, less educated people, and people aged 30–39 years could be target customers for the E2W market.

With regard to e-scooter usage, results indicated that approximately 97.9 % of trial riders who were more likely to adopt an e-scooter and use the BSS tended to use e-scooters in their daily lives to do something nearby (e.g., shopping (76.4 %), picking up children from school (30.7 %), commuting to work (27.9 %), sports and leisure (26.5 %), or other (21.4 %)). Furthermore, e-scooter usage differed slightly according to sex and age. The results showed that men were more likely to ride an e-scooter for shopping, sports and leisure, or picking up children, while women were more likely to use an e-scooter for shopping, picking up children, or commuting to work. With regard to age differences, trial riders aged >29 years were more likely to use an e-scooter for shopping, sports and leisure, or other reasons. Here, promoting an e-scooter as the main means of transport for women, scooter commuters, parents with children, or those needing to travel short distances is suggested. For men, car owners, or those needing to travel long distances to work, an e-scooter product is suggested as their second means of transport. Alternatively, it would be worth considering providing e-scooter leasing services to such groups to substitute their use of high-pollution road transport (e.g., scooters and cars), as well as in their occasional short-distance travel needs.

5.3 System Acceptability

Here, two issues were discussed: social acceptability and practical acceptability. In terms of social acceptability, the convenience factor was identified as influencing riders' willingness to use the BSS. The results showed that most trial riders (97.1 %) found the proposed system convenient. The remaining 2.9 % of trial riders found that the system did not satisfy their needs. The major reason for the latter result is that 30 BSSs are not sufficient, especially when the BSSs are located far from home. In other words, the density of BSSs needs to be increased to improve the convenience to riders. Suggestions have been proposed based on these results, for example, identifying target e-scooter customers and setting up BSSs on frequently traveled routes. In addition, BSSs may be set up at nearby residential, shopping, elementary school, tourist, and sport parks. Furthermore, BSSs may be set up on routes from communities to the above-mentioned areas. The BSS infrastructure, including battery swapping machines, battery chargers, and many extra batteries, is expensive to build. Thus, further research on developing an optimal BSS choice location model is suggested.

With regard to practical acceptability, 635 trial riders (38.3 %) found usability problems, 398 riders (24.0 %) found utility problems, 386 riders (23.3 %) found environment problems, and 237 riders (23.3 %) were not satisfied with the price. These problems were discussed based on the trial riders' qualitative feedback. Firstly, the usability of the proposed system needs to be improved to provide more useful information on the BSS. Since the batteries stored in the station are expensive, the battery swapping system operator preferred to stock the stations with as few batteries as possible. Riders needed extra information to provide them with numbers of fully charged batteries in the BSS, because some riders found there were no fully charged batteries available. Even though the location of the 30 BSSs were summarized and posted at each BSS to help riders decide where next to go, they doubted whether there were batteries available at the next BSS. Such doubts caused them to stop trying. It also shows the importance in developing an ideal number of batteries for the station model, battery reservation service, or innovative service in the near future to lead to better battery swapping system adoption. In addition, several riders were unable to swap their battery on their first try because they found the BSS operating procedure did not match their cognition. They also suggested displaying step-by-step information on the BSS screen while swapping their battery. The above-mentioned information suggests displaying information on the BSS screen, as well as multiple ways of retrieving integrated information technology and communications technology. For example, a 7/24 call center service is suggested to satisfy the information needs of E2W owners, especially for riders who are not part of the network generation. It is expected that riders will receive information via interphone on the BSS, telephone, or mobile phone. In addition, an application service is suggested to satisfy the information needs of riders who have internet connections. It is expected that riders will retrieve information or search for the nearest available BSS via a BSS screen, smartphone, tablet PC, or PC. This also reveals an important issue of BSS capacity limitations, which should be investigated in the near future. Secondly, the system utility needs to be improved by enhancing the design of the connection interface between the battery and the BSS, as well as considering weather problems. Several trial riders could not swap their battery successfully because the connection interface between was not designed properly, causing BSS to not sense the battery after riders dropped the battery off at the station. In such cases, most of the riders did not know what happened. Then, they try to reinsert the battery again. In order to increase riders' understanding and

BSS life, the connection interface and usability (e.g., providing information or signals on BSS screen or battery track to illustrate problems and solutions, or to show whether the battery is placed correctly) should be improved. In addition, most of BSSs were set in open spaces. To provide a good service, self-service BSS should be designed to be applicable in any place and any weather. However, some trial riders encountered were unable to read information on BSS screen because of strong sunlight. Some riders did not want to swap a battery during a rainy day because there was no rain shelter. Hence, waterproofing and anti-glare are important issues in the design of a BSS. Thirdly, the BSS environment should be improved by considering the setting location. In this study, self-service BSSs were set up at public spaces, such as gas stations, scooter parking lots, parks, and sidewalks. Several BSSs set at parking lots, parks, or sidewalks had been skipped by trial riders. The reasons were that BSSs set on sidewalks had a long distance between the e-scooter and the BSS, making it difficult to exchange batteries. Some riders could not use the BSS service because of noncompliance with parking regulations after parking the scooter right in front of the BSS. BSS settings in these locations are limited by local governments. Applying for a public space for a BSS must go through many audit requirements. Therefore, to have full support from local governments and to plan appropriate locations jointly are suggested. Of course, renting private space, such as gas stations and convenience stores, is also an option. The major reason why the battery swapping system operator did not choose this option is to avoid rent expenses. Finally, trial riders needed to know the charging standard before using the BSS service and the charging fee at the time swapping battery. Most trial riders would like to compare the charging fee to the oil price when deciding on the affordability of the swapping service. However, as oil prices have continued to fall in recent years, a new challenge is created by battery swapping fees gradually becoming higher than oil prices. This also shows the importance of finding good countermeasures to overcome the impact of oil prices in the near future. In addition, trial riders were wondering why the charging fee was not shown on BSS screen. After they had been told that they may receive the charging fee and detail information the next time, most of them found the service acceptable. Of course, they further addressed the need to receive immediate information on charging fees. This is another issue that needs to be improved.

6 Conclusion

In this study, a paper-and-pen questionnaire was provided to elicit rider's feedback including personal information, individual traffic demands, exhibit marketing, system acceptability, and purchase intention after he/she had a short period of using the battery swapping system. In order to recruit target audiences (i.e., potential E2W customers), nine exhibitions were held at various destinations in New Taipei City, Taiwan. Each exhibition provided individuals with a free trial ride on an e-scooter. The results of current study indicate that battery swapping system may provide e-scooter owners with a convenient charging service and high degree of system adoption. Although riders found several problems, their acceptance of battery swapping system was not influenced. The viability of this charging service scheme had been demonstrated.

The results may provide reference information for potential e-scooter customers and their needs, battery swapping system design issues, and recommendations to improve future e-transportation projects. In this initial study, individual differences in daily commuting distances, purchase intentions, and e-scooter usage were found. In order to increase the service quality and user satisfaction, and to have better battery swapping system adoption, BSS location, sufficient battery at stations, and easy of use should be investigated further.

Acknowledgments The author would like to express her gratitude to Taiwan Electric Scooter Development Association for setting up exhibitions for this study and Environmental Protection Administration of Taiwan for the funding under the grant number EPA-102-FA13-03A291.

References

1. Tsai, J.H., Hsu, Y.C., Weng, H.C., Lin, W.Y., Jeng, F.T.: Air-pollution emission factors from new and in-use motorcycles. Atmos. Environ. **34**, 4747–4754 (2000)
2. Kirsch, D.A.: The Electric Vehicle and the Burden of History, pp. 153–162. Rutgers University Press, New Brunswick (2000)
3. Li, J.Q.: Transit bus scheduling with limited energy. Transp. Sci. **48**(4), 521–539 (2014). doi:10.1287/trsc.2013.0468
4. Liu, J.: Electric vehicle charging infrastructure assignment and power grid impacts assessment in Beijing. Energy Policy **51**, 544–557 (2012)
5. Worley, O., Klabjan, D.: Optimization of battery charging and purchasing at electric vehicle battery swap stations Chicago. In: IL IEEE Vehicle Power and Propulsion Conference (VPPC), vol. 6–9, pp. 1–4 (Sept 2011)
6. Lombardi, P., Heuer, M., Styczynski, Z.: Battery switch station as storage system in an autonomous power system: optimization issue. In: Minneapolis, MN IEEE Power and Energy Society General Meeting, vol. 25–29, pp. 1–6 (July 2010)
7. Nielsen, J.: Usability Engineering. Academic Press, Cambridge (1993)
8. Malhotra, Y., Galletta, D.F.: Extending the technology acceptance model to account for social influence: theoretical bases and empirical validation. In: Proceedings of HICSS 1999. IEEE Computer Society (1999)
9. Goffman, E.: The Presentation of Self in Everyday Life. Penguin Books, London (1990)
10. Grudin, J.: Utility and usability: research issues and development contexts. Interact. Comput. **4** (2), 209–217 (1992)
11. Bevan, N., Kirakowski, J., Maissel, J.: Proceedings of the 4th International Conference on HCI, Stuttgart. http://www.nigelbevan.com/papers/whatis92.pdf (1991)
12. ISO 9241-11: International standard first edition. Ergonomic requirements for office work with visual display terminals (VDTs). Part 11: Guidance on usability. http://www.idemployee.id.tue.nl/g.w.m.rauterberg/lecturenotes/ISO9241part11.pdf (1998)
13. Wood, E.H.: Evaluating event marketing: experience or outcome? J. Promot. Manage. **15**(1–2), 247–268 (2009)
14. Smilansky, S.: Experiential Marketing: A Practical Guide to Interactive Brand Experiences. Kogan Page, London (2009)

15. Pine II, B.J., Gilmore, J.H.: Welcome to the experience economy. Harvard Bus. Rev. **76**(4), 97–105 (1998)
16. Holbrook, M.B., Hirschman, E.C.: The experiential aspects of consumption: consumer fantasy, feelings and fun. J. Consum. Res. **9**(2), 132–140 (1981)
17. Hirschman, E.C., Holbrook, M.B.: Hedonic consumption: emerging concepts, methods and propositions. J. Market. **46**, 92–101 (1982)
18. Schmitt, B.: Customer Experience Management: A Revolutionary Approach to Connecting with Your Customer. Wiley, New Jersey (2003)
19. Caru, A., Cova, B.: Revisiting consumption experience: a more humble but complete view of the concept. Markt. Theor. **3**(2), 267–286 (2003)

Building an Inclusive Ecosystem for Developers and Users: The Role of Value Propositions

Katerina Touliou and Evangelos Bekiaris

Abstract For many years, work in the area of accessibility was focusing on making a product accessible or the internet experience accessible for people with disabilities. Currently, a paradigm shift is happening within the EU project Prosperity4All (http://www.prosperity4all.eu/), bringing together developers and users in order to make every ICT experience personalized and customized. A priori a set of value propositions for developers were set. These value propositions were initially tested during an-hour session with developers. A semi-structured questionnaire with 45 items was used, addressing the infrastructure's value for their work and progress. Developers were interested to learn from other experts and share documentation but they were more interested to learn directly from end-users by establishing frequent communication. They strongly believe this is the cornerstone of customized solutions and technologies should support and cover this need on demand. Re-usability of knowledge was the most important cost-efficient value.

Keywords Inclusive ecosystem · Developers · Value propositions · Accessibility

1 Introduction

For many years, work in the area of accessibility was focusing on making a product accessible or the internet experience accessible for people with disabilities. Currently, a paradigm shift is happening within the EU project Prosperity4All

K. Touliou (✉) · E. Bekiaris
Centre for Research and Technology Hellas (CERTH), Hellenic Institute of Transport (HIT), 57 001 Thessaloniki, Greece
e-mail: touliouk@certh.gr

E. Bekiaris
e-mail: abek@certh.gr

M. Soares et al. (eds.), *Advances in Ergonomics Modeling, Usability & Special Populations*, Advances in Intelligent Systems and Computing 486,
DOI 10.1007/978-3-319-41685-4_30

(http://www.prosperity4all.eu/), bringing together developers and users in order to make every ICT experience personalized and customized. The goal is to develop and deploy a new, broad-ranging, cloud-based infrastructure that makes the Internet more accessible for users with accessibility needs. The new ‘ecosystem’ enables people previously excluded from ICT to get help using technology and aims to use their feedback to develop new apps and services. The developers, on one hand, will be able to find tools and learn about accessibility, find customers, be part of the community and, users, on the other hand, will be able to get a customized solution or service to their needs.

Although it has been argued that a combination of systems, services or software can never be an ecosystem [1], the main assumption is that the different parts do constitute an ecosystem because the persons who will populate it they will do it with intention and ethics. The different parts of the ecosystem will interact through the exchange of information, resources and artifacts [2]. The ecosystem should be flexible enough to accommodate for real interactions and self-sustainable and self-regulated growth. To do so, two things are essential to take into account: (a) the interchangeability of roles for the actors of an ecosystem, and (b) the value propositions for the actors we wish to be part of the community and the ecosystem. In order for the ecosystem to be created, then the infrastructure first needs to be populated with people who wish to develop for people with accessibility needs.

The structure of the ecosystem needs to be supported by established mechanisms that will facilitate development and marketing and minimize friction with other professionals and end-users. The interaction with the ecosystem will reveal also their development styles and their preferences towards certain categories of components over others and if/how it is affected by specific components.

Value propositions might be different for each developer as a person, as a professional and/or organization. An important consideration is user reach (i.e. how many users they will reach/engage with their product as a result of joining the project’s ecosystem).

Interaction of developers with the ecosystem will be evaluated based on the following elements:

- Discovery (find, learn, choose);
- Distribution (use, deploy, share);
- Monetization (minimize cost, effort, increase in user experience Return-on Investment (ROI)) (Fig. 1).

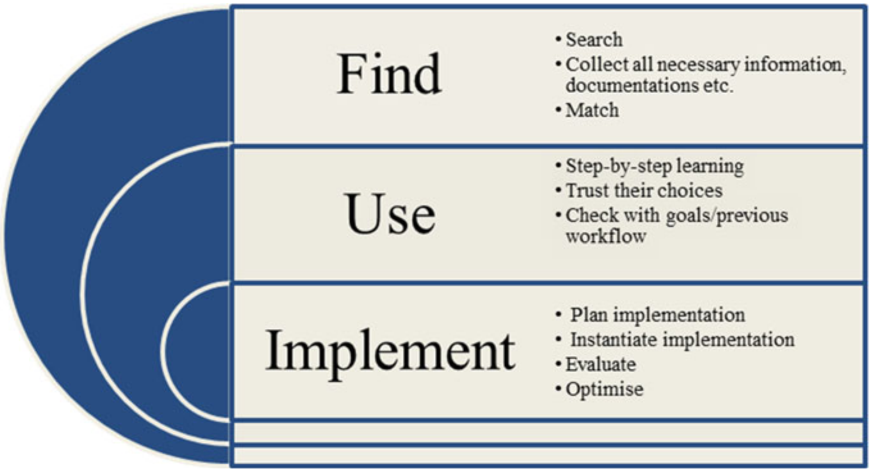


Fig. 1 The steps of the implementation process within P4A

2 Methodology

Affinity groups are groups of people who come together to discuss and share common problems. The structure and organization of affinity groups appear to be effective in problem solving in areas other than social and psychological support. In this method the structure of the focus group remains; people form small groups of 5–6 individuals to solve a problem or an exercise. Usually a whiteboard and colored stickers are used to show interactions, relations, and dynamics. This formative method shares many common practices with brainstorming sessions. They are very helpful in revealing how the researcher's expectations match the expectations of the target user groups or participants. They are moderated sessions with one or two facilitators and participants are given an exercise to solve or a task to complete. They can write on the Post-its® and place them either on a whiteboard or a diagram to show their mapping of the process or their decision. The common exercise often surfaces the group dynamics, patterns of use and attitudes towards use and usefulness.

A priori a set of value propositions for developers were set. These value propositions were initially tested during an-hour session with developers who are already working in the project and high level visualizations of the ecosystem was used, depicting major entry-points and ways different user groups can interact with the ecosystem. A semi-structured question pool with 45 items was used, addressing the infrastructure's value for their work and progress.

Value propositions for developers were actually investigated for the following three aspects:

- **Learn (up-to-date)** is about acquiring knowledge, know-how and finding up-to-date resources.

- **Use** of knowledge and experience to other application areas.
- **Gain** is actually what they can earn/attain/acquire by their interaction and work carried out within the project.

2.1 Participants

The focus group session was conducted with five internal developers. However, two of them are not involved in the project and they were informed about the objectives and aims of the project. A small group of professionals was chosen who know each other fairly well and they were invited to work together as they would normally collaborate to solve a programming problem or issue. Three of them are senior programmers and two have low to medium experience. They all have different backgrounds and all are under 40 years old (age range: 34–39).

2.2 Procedure

The session carried out with internal developers aimed to reveal their interactions with the higher level of the ecosystem and what they are expecting to gain (value) from their involvement in this project. The session was conducted to explore the realism and validity of initial interaction and value propositions. It is kept in mind that they cannot be validated with just one session with internal developers and the results presented in this paper are preliminary and further evaluations will be conducted later in the project.

3 Results

3.1 Learn

Developers are interested to learn not only from other experts and documentation but they are really interested to learn directly from end-users. They strongly believe this is the cornerstone of customized solutions. All partners agreed that information received was in the majority of cases up-to-date. The direct collaboration with the teams was perceived as the most useful aspect so far and that its seamless operation directly affects the required development effort and time.

Knowledge in accessibility increased not because they have access to the components they are using only but because they have access to so much information they did not even use (e.g. learn about other tools and components, communicate with other teams working in different accessibility areas than the ones they have already used). A commercial developer reported that if they did not participate in the project, they might have integrated a similar component but with limited functionalities and control options but they would not have the change to use this component due to copyright restrictions.

Developers mentioned that they acquired knowledge not only from the integration process but also from generally searching the shared wiki pages. For now, knowledge will be used for the work to be carried out (e.g. continue the integration process or use another component). Re-usability of knowledge largely depends on language used.

3.2 Use

Use of know-how is still not clear. They are positive that it will give them "know-how" but they do not know how exactly they will apply this newly acquired knowledge to future development work. Participants who have finished (or are close to finishing) integration, they have decided which components to integrate next. Therefore, the use of the knowledge to be acquired, it will be used mostly for the work to be performed within the project and in some cases targets different modalities (diversify functionalities) or other end-user groups (i.e. expand target user groups). Use of language came up as a common part of the work that will be re-used in other projects.

One developer mentioned that increase in accessibility knowledge will help them offer a better and profitable accessibility service.

3.3 Gain

For commercial developers, offering their service through the Prosperity4All ecosystem is an added value but not the main value. It is considered an additional promoting channel apart from the company's marketing plan.

For developers, who closely work with end-user organizations, enhancing existing applications or services is an opportunity to offer more to end-users in situations where there is no budget to achieve this otherwise. For some participants, obtaining the components they needed was feasible only through the shared spaces, as there was no budget to allocate for furthering development work. Remaining resources were primarily consumed for maintenance. Thus, being part of an ecosystem will offer them an opportunity to improve their work when they could not have done it otherwise.

For one partner, developing within the ecosystem will give them the opportunity to benchmark similar product they have developed in the past and compare it with the component they are using within the project (i.e. test their own products). The potential to open up the product to different control methods, and used by other

Table 1 Important aspects in development process per developer background

Professional area	Important areas
Commercial	Decrease development Decrease development effort Collaborate with other developers Increase types of users they can reach
Volunteer	Up-to-date knowledge Research publications Increases number of users reached
Open-source	Increases number of users reached Increase type of users reached Decreases development effort

groups of end-users in such a way that is very easy and with hardware that every user has in their pc, is a strong incentive and gain for developers.

For three developers, the use of the component so far, will expand the types of end-users they may attract. One developer mentioned that although they currently focus on satisfying the needs of developers, a service for direct communication between end-users and developers/developers would be extremely helpful. End-users will be able to get assistance and report problems and additionally developers might be able to learn what went wrong with their product when end-users stop using it (i.e. they usually abandon the product and move on to another one than contact the developer or for assistance and the developers never get to know what went wrong with this product). Such feedback is relevant to the other two value propositions for developers; the developer learns by their mistakes and uses the acquired knowledge for resolving these and similar mistakes and errors in future work. A company developer mentioned that there is no gain for them offering their improved product as an open-source and even if they wanted to, the effort and resources required to do so do not exist (for such adaptation) and any changes it might bring.

Developers suggested that they have to collaborate on building a common strategy to maintain and support the different parts of the ecosystem. Adding components is a first step but the second, and equally important, is including up-to-date and useful components. This will not be achieved during the lifetime of the project and, therefore, developers suggested that maintenance should be connected to a follow-up project dedicated to the growth, enrichment, and in populating the ecosystem. One developer stressed that based on past experience, if abandoned, a developer-based community will most probably collapse pretty soon with 40 % of each components rendered useless within the first two years.

The following table briefly presents the areas of importance per professional development background (Table 1).

4 Conclusion

Developers are interested to learn not only from other experts and share documentation but they are really interested to learn directly from end-users. They strongly believe this is the cornerstone of customized solutions. Re-usability of knowledge largely depends on language used and it is considered a very valuable "wild card".

For commercial developers, offering their service through the ecosystem is an added value but not the main value. It is considered an additional promoting channel apart from the company's marketing plan.

Developers used the following words to characterize what they gained so far:

- Professional satisfaction
- User engagement
- Broader use
- Benchmarking

End-users will be able to get assistance and report problems and additionally developers might be able to learn what went wrong with their product when end-users stop using it (i.e. they usually abandon the product and move on to another one than contact the developer or for assistance and the developers never get to know what went wrong with this product). Communication and collaboration are of key importance for both ends in deciding being part of such an ecosystem.

Thus, knowledge is important but not as important as collaboration. Developers pointed out that based on their past experiences, a developer-based community, if abandoned, will most probably collapse pretty soon. Therefore, offering flexible, adaptable and porous communication, collaboration and interaction points seems to be a valid and fruitful value propositions for both user groups.

The developers expect the ecosystem to be a highly innovative place. They need (direct) contact to end-users in order to be able to develop user-centered systems/software. Therefore, they want to use the infrastructure rather than understand the underlying structure in detail.

A need to "open-up" the infrastructure to experts and communicate our designs with people is evident, especially for the searching and deployment process. The development process seems to be at the moment mostly individually- and development-centered. This is happening mainly because major functional parts of the project's infrastructure are still to be designed and developed.

Acknowledgments This paper presents work carried out in Prosperity4All project. This project has received funding from the European Union's Seventh Framework Programme for research, technological development and demonstration under grant agreement no. 610510. http://www.prosperity4all.eu/

References

1. Free Software, Free Society.: The Selected Essays of Richard M. Stallman. https://www.gnu.org/philosophy/words-to-avoid.html#Ecosystem
2. Messerschmitt, D.G., Szyperski, C.: Software Ecosystem: Understanding an Indispensable Technology and Industry. MIT Press, Cambridge, MA, USA (2003)

A Taiwanese User Experience Questionnaire

Yu-Hung Chien, Wen-Te Chang, Ching-Chang Chuang and Shun-Han Chen

Abstract The use of questionnaires is an efficient and inexpensive method to measure user experience. Existing user-experience questionnaires developed based on Western populations and cultures. Given that cultural differences can influence judgments and the experience of products, questionnaires on user experiences based on Western cultures are not necessarily universal. Therefore, the aim of this study was to develop a Taiwanese User-Experience Questionnaire (TUEQ) with semantic differential techniques to understand the experience of Taiwanese users in relation to interactive digital products. A 23-item TUEQ was constructed in this study. The TUEQ identifies four main dimensions contributing to the experience of Taiwanese users: pragmatic quality, general hedonic quality, contemporary hedonic quality, and unique hedonic quality. The practical implications of the TUEQ and further study needed for a satisfactory level of reliability and construct validity are discussed.

Keywords Culture · Questionnaire · User experiences

1 Introduction

There is a common view that "user experience" constitutes a more widely inclusive property for improving interactive digital products than obtaining usability feedback from users. Literally, a good user experience is central to the success of interactive digital products.

Y.-H. Chien (✉) · S.-H. Chen
Department of Technology Application and Human Resource Development,
National Taiwan Normal University, Taipei, Taiwan
e-mail: roland.chien@ntnu.edu.tw

W.-T. Chang
Department of Art and Design, National Taipei University of Education,
Taipei, Taiwan

C.-C. Chuang
Department of Product Design, Ming Chuan University, Taoyuan, Taiwan

M. Soares et al. (eds.), *Advances in Ergonomics Modeling, Usability & Special Populations*, Advances in Intelligent Systems and Computing 486,
DOI 10.1007/978-3-319-41685-4_31

Generally, usability is often associated with the functionality of products and can be tested by a usability test or an expert review. A well-known example, focusing on effectiveness, efficiency, and learnability, is the heuristic evaluation formulated by Molich and Nielsen [16]. In contrast, user experience describes the whole impact a product has on end users. The concept of user experience combines aspects of efficiency and effectiveness with additional criteria, such as esthetics [11], joy-of-use [7], and emotions [18]. The goal of determining user experience differs from that of the more objective factor, usability. User experience is more concerned with how users experience an interactive digital product from their perspective, rather than assessing how useful or productive a system is from its own perspective. Preece et al. [20] showed a possible relationship between usability and user experience (Fig. 1). Accordingly, user experience should be separated into two groups of criteria. The first is referred to as 'aspects of pragmatic quality', while the second group is called 'aspects of hedonic quality' [3].

A product has its own features, chosen and combined by a designer, to convey an intended product character [9, 17]. The character describes a product's attributes [5]. People perceive the product's features and construct a personal version of the product character. This character, consisting of groups of pragmatic and hedonic attributes, leads to a judgment about the product's appeal [5]. The dependency of the pragmatic and the hedonic quality is presented in Fig. 2. Consequently, it is necessary to consider aspects of both pragmatic and hedonic quality to understand the satisfaction of users with a given product.

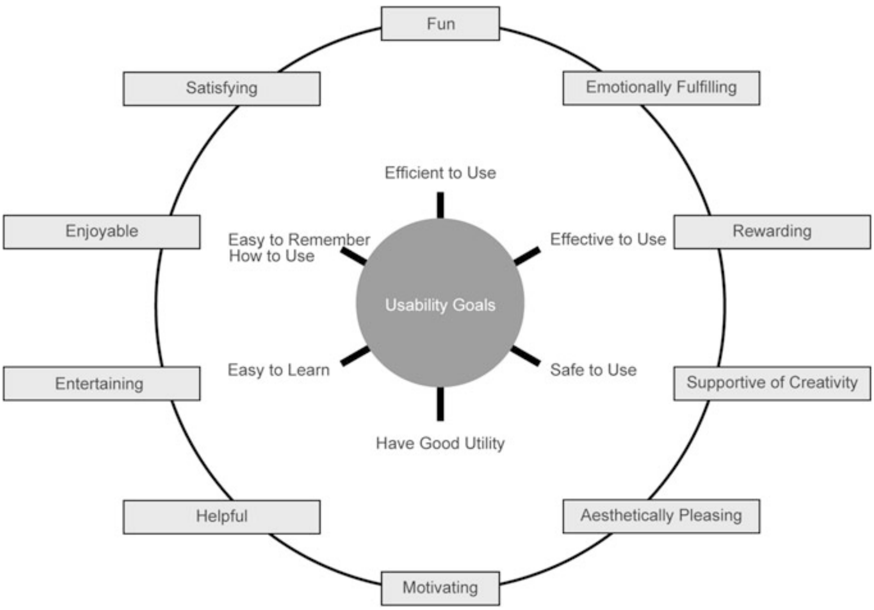


Fig. 1 Relationship between usability and user-experience goals [20]

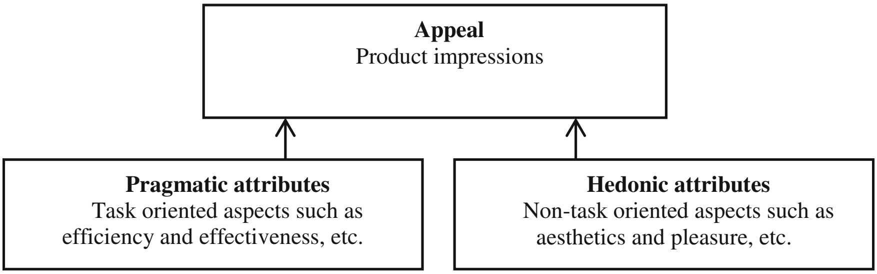


Fig. 2 Dependency of pragmatic and hedonic quality

Feedback from stakeholders, like developers, managers, and users, is needed to optimize interactive digital products. An efficient and inexpensive method to measure user experience is the use of questionnaires. Several questionnaires have been developed, such as QUIS (Questionnaire for User Interaction Satisfaction) [2], SUMI (Software Usability Measurement Inventory) [10], CSUQ (Computer System Usability Questionnaire) [14], and SUS (System Usability Scale) [1]. These questionnaires focus on usability criteria in a narrower sense, corresponding roughly to the concepts of usability goals [20] or pragmatic quality [6]. More recent approaches increasingly give attention to subjective reactions. There are two well-known existing questionnaires that measure user experience: AttrakDiff [4] and UEQ [13]. A special feature of these two questionnaires is the use of semantic differentials scaling [19]. Semantic differentials are well known in attitude research; this approach uses contrary adjectives or nouns among which participants locate their answer.

AttrakDiff was originally developed in German. It has four dimensions (hedonic stimulation and identity, pragmatic qualities, and appeal), seven anchor scales and, in total, 28 questions, such as dull-captivating, tacky-stylish, cumbersome-straightforward, and ugly-attractive. The anchors of AttrakDiff are presented on opposite sides of a seven-point Likert scale, ranging from −3 to 3, where zero represents the neutral value between the two anchors of the scale.

UEQ consists of 26 items assigned to six dimensions (attractiveness, quality of hedonic efficiency, hedonic perspicuity, and hedonic dependability, quality of pragmatic stimulation and pragmatic novelty). The items are also scaled from −3 to 3. UEQ was also originally developed in German [12].

It is especially important for users to develop items using their native language for semantic differentials [21] because the meaning of words used for each item will differ from culture to culture [15]. AttrakDiff and UEQ were developed by collecting adjective and noun pools based on Western language and culture. The adjectives and nouns used in their questionnaires might not reflect Taiwanese users' experiences with interactive digital products.

Although UEQ has offered a Chinese version on a website (http://www.ueq-online.org), and the Chinese version was translated based on simplified Chinese, there are still language and culture difference issues between Chinese and

Taiwanese. The simplified Chinese translated UEQ might not be suitable for Taiwanese users. For example, the word “conventional”, which appeared in the UEQ was translated into simplified Chinese as “常规的,” which is recognized as the word “routine” by the Taiwanese. The word “傳統的” is a more suitable term for “conventional” for Taiwanese users. The former is apparently misleading, and would need to be avoided. Moreover, Yeh et al. [22] compared the use of a nine-point hedonic scale between American and Taiwanese and reported that Taiwanese would avoid extreme responses and would be polite and not express negative responses (e.g., psychological error in leniency) on extremely negative words.

AttrakDiff and UEQ were developed by collecting an adjective pool based on the feelings of Westerners. The words used in their questionnaires might not be suitable to measure Taiwanese users’ feelings because the words used might be too extreme or strong. Moreover, the characteristics of user experiences in hedonic quality are more related to non-functional aspects, which could differ from culture to culture. The cultural dimensional model of Hofstede et al. [8], a major resource in the cross-cultural field, distinguished cultures according to six dimensions: power distance, individualism/collectivism, masculinity/femininity, uncertainty avoidance, long-term orientation, and indulgence. Comparing Taiwanese and German using the cultural dimensional model, there are many differences between the two populations in most of the dimensions, except uncertainty avoidance.

Consequently, the aim of this study was to construct a Taiwanese User Experience Questionnaire (TUEQ) to allow a quick assessment of Taiwanese user experience with an interactive digital product. The questionnaire was designed to cover a comprehensive impression of Taiwanese user experience, and the format of the questionnaire should support Taiwanese users in immediately identifying feelings, impressions, and attitudes that arise when they use an interactive digital product.

2 Method

TUEQ was constructed in three phases: (1) generating a pool of potential items, (2) examining the specific properties of the adjective pairs concerning the assessment of interactive digital products, and (3) reducing items by a factor analysis.

2.1 Generation of the Item Pool

Relevant research reports were reviewed to collect Taiwanese terms that could represent the characteristics for the assessment of user experience. In total, 1297 adjective pairs were collected from 57 papers related to user experience and 609 adjective pairs were left after deleting repeated terms. Then, 10 usability experts were invited to individually extract a "top 25" list from the whole set of adjective pairs. Adjective pairs that were selected by experts twice were kept, and a set of 56 adjective pairs remained. Finally, a database management system for Chinese antonyms developed by the Institute of Linguistics, Academia Sinica, was used to check the fit of antonyms on each of the 56 adjectives pairs. Six adjective pairs were adjusted, e.g., beautiful (美的)-unbeautiful (不美的) was replaced by beautiful (美的)-ugly (醜的) because the meaning between beautiful and ugly was more mutually exclusive than that between beautiful and unbeautiful. Pleasant (愉快的)-angry (生氣的) was replaced by pleasant (愉快的)-displeasing (不愉快的), because many words represent opposite meanings of the word pleasant.

2.1.1 Data Collection

To examine the specific properties of the adjective pairs concerning the assessment of interactive digital products, the 56-item raw version of the scale was used in three investigations.

Apple Mac Book (laptop): Forty university students were recruited to complete two tasks using an Apple Mac Book. The first was to convert a PDF into a Word file. The second task was to activate a clock alarm at a specific time with specific music. These applications then were evaluated by the participants using the 56-item questionnaire.

Apple iPad Air (tablet PC): Forty university students were recruited to complete two tasks using an Apple iPad Air. The first was to play the app game of Cooking Fever. The second task was to open the app OneNote, establish a new note, insert a picture into the note, and then close the app. Each of the participants worked actively with the apps and then completed the questionnaire.

Acer Liquid Jade and Liquid Leap (smart phone and smart bracelet): Forty university students were recruited and were asked to use a Liquid Jade and a Liquid Leap to complete two tasks. The first was to wear the Liquid Leap, connect the Liquid Leap with Liquid Jade, start the pedometer app, walk 20 steps, and check the information on distance and steps on the display of the Liquid Leap. The second task was to play a song with Liquid Jade and control the volume of the music using the Liquid Leap. Participants filled out the questionnaire after finishing the two tasks.

In total, 120 participants provided complete datasets. Those data were used for the process of item reduction.

2.1.2 Reduction of the Item Pool

Item-total correlations

To delete items that did not measure the same qualities as the whole scale, the original 56 items were analyzed by correlation analysis to establish acceptable item-total correlations. A low correlation indicated that the item did not measure the same qualities as the whole scale. The criterion for item reduction was that the item-total correlation was significant ($p < 0.05$) and items with item-total correlation coefficients below 0.3 were eliminated. Consequently, seven items were deleted and 49 items remained.

Exploratory factor analysis
A factor analysis (principal components, varimax rotation) was performed; the result showed KMO = 0.84. The level was significant, meaning the data were suitable for factor analysis. The scree test was used to determine the number of factors. Four factors with eigenvalues greater than 1.0 emerged and some items were reduced with the following criteria. First, the loading of each item on the main factor should be >0.5, meaning they measure the same quality as other items do. Second, items with loading >0.5 on two or more factors were deleted, so items measuring two or more factors were not included. Finally, 23 items remained (Table 1).

As illustrated in Table 1, four main principal components or factors were identified after the exploratory factor analysis. Factor 1 was the general hedonic quality dimension, Factor 2 and Factor 3 were also considered to be hedonic quality dimensions, but were more specific for contemporary quality and unique quality, and Factor 4 was the pragmatic quality dimension.

3 Validation of the Questionnaire

According to Hassenzahl [3], users' task difficulty rating can be used as a good validity measure against the user experience rating of a product. For example, if users spend relatively more mental effort in completing a task, then the product is less likely to be usable and quite likely will have a low pragmatic quality score. Also, hedonic quality is not related to the task, so there should be no relationship between the task difficulty rating and the hedonic quality rating.

Consequently, a usability study has been planned and will be performed soon concerning the validity of the questionnaire by exploring differences in the experience of Taiwanese users in interacting with the operating systems Windows 7, Windows 8, and Windows 10. Participants will be asked to rate the degree of difficulty after completing the requested tasks with the three operating systems and then complete the TUEQ. Examining the relationship between the rating of the degree of difficulty and the scores of TUEQ and the value of Cronbach's α coefficient will be calculated to assess the validity and reliability of the TUEQ.

Table 1 Loadings of the 23 items in four identified principal components after the exploratory factor analysis

	Hedonic quality			Pragmatic quality
	General	Unique	Contemporary	
有趣的(Interesting)-乏味的(Boring)	0.761			
優閒的(Leisure)-忙碌的(Busy)	0.706			
熱情的(Zealous)-冷漠的(Apathetic)	0.701			
喜歡的(Like)-討厭的(Bothersome)	0.638			
愉快的(Pleasant)-不快的(Unpleasant)	0.624			
自在的(Free)-拘束的(Restrained)	0.563			
舒適的(Comfortable)-難受的(Uncomfortable)	0.545			
獨特的(Unique)-普通的(Ordinary)		0.752		
創新的(Innovative)-守舊的(Conservative)		0.709		
高雅的(Elegant)-粗俗的(Inelegant)		0.630		
尊貴的(Superior)-卑微的(Humble)		0.604		
時髦的(Fashionable)-過時的(Out-of-date)		0.545		
新奇的(Novel)-陳腐的(Stale)		0.539		
先進的(Advanced)-落後的(Backward)			0.785	
未來的(Future)-往昔的(Past)			0.771	
現代的(Modern)-古代的(Ancient)			0.650	
都會的(Urban)-田園的(rural)			0.632	
光滑的(Smooth)-粗糙的(Rough)			0.598	
節省的(Economical)-奢侈的(Luxurious)				0.714
省力的(Effortless)-費力的(Laborious)				0.660
實用的(Practical)-不實用的(Impractical)				0.611
便利的(Convenience)-麻煩的(Inconvenience)				0.595
整齊的(Tidy)-紊亂的(Chaotic)				0.511

4 Discussion and Conclusions

A 23-item TUEQ assessing Taiwanese user' experience of an interactive digital product has been developed. The initial version of TUEQ has dimensions of pragmatic quality, general hedonic quality, contemporary hedonic quality, and unique hedonic quality. All three user-experience questionnaires, AttrakDiff, UEQ, and TUEQ, consider that pragmatic and hedonic aspects are important factors for user experience in relation to the appeal of an interactive digital product. That is, hedonic and pragmatic qualities have explained variance in predicting the overall appeal, which calls for an integrative approach to product design. Product designers should take simultaneous account of these two properties, and might need to consider their mutual influence on each other.

It would also be wise to review attributes to ensure correct comprehension across different cultures. In this study, two new dimensions in TUEQ that differ from those of AttrakDiff and UEQ were found. Accordingly, it suggested that designers should give priority to different aspects of user experience, to develop products that will be perceived as appealing by users with different cultural backgrounds. Beyond general hedonic quality and pragmatic aspects, Taiwanese users placed more emphasis on the contemporary quality and uniqueness of the product. Accordingly, industries targeting the Taiwanese market need to focus not only on promoting perceived effectiveness and efficiency but also emphatically to advertise aspects like the product's novelty, innovation, and the advances it offers.

The TUEQ questionnaire will be placed online and will be available for use free of charge. The questionnaire itself, a data analysis tool, and literature describing the construction of the questionnaire will be downloadable in the future. Hopefully, more Taiwanese users from different backgrounds and age groups will use the questionnaire to increase its validity.

Acknowledgments The authors gratefully acknowledge the financial support provided by the Ministry of Science and Technology of the Republic of China under Project MOST 103-2410-H-003-126.

References

1. Brooke, J.: SUS: a "quick and dirty" usability scale. In: Jordan, P.W., Thomas, B., Weerdmeester, B.A., McClell, I.L. (eds.) Usability Evaluation in Industry, pp. 189–194. Taylor and Francis, London (1996)
2. Chin, J.P., Diehl, V.A., Norman, K.L.: Development of an instrument measuring user satisfaction of the human-computer interface. In: SIGCHI Conference on Human Factors in Computing Systems, pp. 213–218. ACM (1998)
3. Hassenzahl, M.: The effect of perceived hedonic quality on product appealingness. Int. J. Hum-Comput. Int. **13**, 481–499 (2001)
4. Hassenzahl, M.: The interplay of beauty, goodness, and usability in interactive products. Hum. Comput. Int. **19**, 319–349 (2004)

5. Hassenzahl, M.: The thing and I: understanding the relationship between user and product. In: Funology, pp. 31–42. Springer, Netherlands (2005)
6. Hassenzahl, M., Burmester, M., Koller, F.: AttrakDiff: Ein Fragebogen zur Messung wahrgenommener hedonischer und pragmatischer Qualität. In: Mensch & Computer, pp. 187–196. Vieweg+ Teubner Verlag (2005)
7. Hatscher, M.: Joy of use-Determinanten der Freude bei der Software-Nutzung. In: Mensch & Computer, pp. 445–446. Vieweg+ Teubner Verlag (2001)
8. Hofstede, G., Hofstede, G.J., Minkov, M.: Cultures and organizations: software of the mind: intercultural cooperation and its importance for survival, 3rd edn. McGraw Hill, New York (2010)
9. Janlert, L.E., Stolterman, E.: The Character of things. Des. Stud. **18**, 297–314 (1997)
10. Kirakowski, J., Corbett, M.: SUMI: the software usability measurement inventory. Brit. J. Educ. Technol. **24**, 210–212 (1993)
11. Laugwitz, B.: Experimentelle Untersuchung von Regeln der Ästhetik von Farbkombinationen und von Effekten auf den Benutzer bei ihrer Anwendung im Benutzungsoberflächen Design. Dissertation. de-Verlag im Internet, Berlin (2001)
12. Laugwitz, B., Schrepp, M., Held, T.: Konstruktion eines Fragebogens zur Messung der User Experience von Softwareprodukten. In: Mensch & Computer, pp. 125–134. Vieweg+ Teubner Verlag, Berlin (2006)
13. Laugwitz, B., Held, T., Schrepp, M.: Construction and Evaluation of a User Experience Questionnaire, pp. 63–76. Springer, Berlin (2008)
14. Lewis, J.R.: IBM computer usability satisfaction questionnaires: psychometric evaluation and instructions for user. Int. J. Hum-Comput. Int. **7**, 57–78 (1995)
15. Maclay, H., Ware, E.E.: Cross-cultural use of the semantic differential. Behav. Sci. **6**(3), 185–190 (1961)
16. Molich, R., Nielsen, J.: Improving a human-computer dialog: what designers know about traditional interface design. Commun. ACM **33**, 338–348 (1990)
17. Mono, R.W.: Design for product understanding: the aesthetics of design from a semiotic approach. Liber AB, Stockholm (1997)
18. Norman, D.: Emotional Design: Why We Love (or Hate) Everyday Things. Basic Books, New York (2004)
19. Osgood, C.E.: Method and Theory in Experimental Psychology. Oxford University Press, New York (1953)
20. Preece, J., Rogers, Y., Sharp, H.: Interaction Design: Beyond Human-Computer Interaction. Wiley, New York (2002)
21. Rauschenberger, M., Schrepp, M., Cota, M.P., Olschner, S., Thomaschewski, J.: Efficient measurement of the user experience of interactive products. How to use the user experience questionnaire (ueq). Example: spanish language version. Int. J. Interact. Multimed. Artif. Intell. **2**(1), 39–45 (2013)
22. Yeh, L.L., Kim, K.O., Chompreeda, P., Rimkeeree, H., Yau, N.J.N., Lundahl, D.S.: Comparison in Use of the 9-point Hedonic Scale between Americans, Taiwanese, Koreans, and Thai. Food Qual. Prefer. **9**(6), 413–419 (1998)

Gesture Preference with Horizontal and Vertical Multi-touch Devices

Robert Regal, Joshua Gomer and Kristin Moore

Abstract This study examined gesture preferences for a vertical or horizontally-oriented multi-touch input device. Gesture interfaces have become prevalent, increasing the need to characterize technology expectations. The current study expanded previous work (Morris in Proceedings of graphics interface, 2010), which identified preference of a gesture for a given command. Forty employees from Space and Naval Warfare Systems Center Atlantic participated. Twenty-one participants were tested with a vertical multi-touch device while 19 were tested with a horizontal multi-touch device. For a subset of commands (duplicate, enlarge, rotate), orientation was a factor in gesture preference. A subset of gestures was preferred with a vertical orientation and another subset preferred with a horizontal orientation. Users indicated that gestures were relatively easier in the vertical orientation compared to horizontal. Orientation should be considered when designing command gestures for multi-touch devices. Potential applications of this research include design of gesture commands for future multi-touch systems.

Keywords Touch screen · Orientation · Human factors · Human systems integration · Human computer interaction · Multi-touch

The opinions, conclusions, and recommendations expressed or implied are those of the authors and do not necessarily reflect the views of the U.S. Naval War College, the Department of the Navy, or the Department of Defense.

R. Regal · J. Gomer (✉)
Space and Naval Warfare Systems Center Atlantic, Charleston, SC, USA
e-mail: Josh.Gomer@Navy.mil

R. Regal
e-mail: Robert.Regal@Navy.mil

K. Moore
Google, New York, NY, USA
e-mail: KristinSMoore@Gmail.com

M. Soares et al. (eds.), *Advances in Ergonomics Modeling, Usability & Special Populations*, Advances in Intelligent Systems and Computing 486,
DOI 10.1007/978-3-319-41685-4_32

1 Introduction

In 2007, Space and Naval Warfare Systems Center (SPAWARSYSCEN) Atlantic purchased a large (96″ × 36″) multi-touch screen from Perceptive Pixel, Inc. (New York, NY). Following this procurement, an internally funded research program began investigating the potential benefits of multi-touch and large form factor screens. The program developed multiple widgets demonstrating novel multi-touch Tactical Decision Aids (TDAs), including Range and Bearing, Closest Point of Approach, and Quick Intercept. This new multi-touch, multi-user (MTMU) interface became a regular point of interest among command VIPs, including a chairman from the U.S. Naval War College (War College) War Gaming Department (WGD). After participating in a demonstration, the chairman became convinced that this new multi-touch interface could help him improve the war gaming process. He felt that there were several benefits inherent to the multi-touch user interface (UI), including potentially reducing costly training time while also allowing for more productive war gaming sessions. Further, and perhaps of greatest interest to the chairman, multi-touch had the potential to capture more war gaming process data, which could foster superior, parallel analysis.

Prior to beginning development for the War College, SPAWARSYSCEN Atlantic spent a significant amount of time observing and participating in games at the WGD before finalizing the first software design. Within one year, an initial prototype feature set was delivered, which included the previously mentioned TDAs. Over the next five years, developer travel commenced roughly once a month to the War College to support agile development of this prototype. Five years later, the War College was using a mature SPAWARSYSCEN multi-touch application that is currently featured in multiple war games each year. The current version has the ability to share layers of data, allows visibility of actions that are taking place on other MTMUs, supports pushpin grouping, provides a globe widget, supports "undo", and ad hoc note taking. To date, the War College has purchased 13 multi-touch systems that run this application. Incorporation of multi-touch at the War College has reduced training time and permitted some restructuring of the games. For example, the parallelism inherent in the design of the multi-touch systems has helped reduce the segmentation of game "moves." All adjudication cells have awareness of the planning conducted in other cells, which aids judges in plotting out the reactions to the player activities instead of submitting moves at the end of a defined period. This increased awareness allows the adjudication cell to respond more quickly, increasing the number of moves permissible in a game, leading to higher game fidelity.

Somewhat in parallel to this development, a 2009 study [10] examined participant interaction with various input devices including virtual objects on a tabletop touch screen, physical objects on a tabletop, and a desktop computer with mouse. The goal was to determine how multi-touch interfaces affect the way users manipulate objects and examine differences in performance across different platforms. Without training, participants were asked to select and move colored circles into different groupings. Actions were recorded and coded for different gesture types across input devices. This study found that performance with the physical surface was faster than the tabletop multi-touch. Additionally, participants who had the physical condition first were faster on the multi-touch than those who did not. Overall, performance with the multi-touch was faster than the desktop computer. Gesture preference results supported that developers should consider dispositional expectations of users and expectations of interaction with multi-touch surfaces. The study concluded by cautioning future designers of tabletop interfaces in finding a good balance between physical metaphors and supporting gestures to invoke automation. A more recent study [5] corroborated the finding that gestures will be influenced not only by user preferences, but also by interaction and social context.

As MTMU interfaces increase in popularity, developers will need to focus on creating more intuitive, usable gestures to allow for seamless user interaction. Removing a mouse or joystick removes a level of interaction abstraction for a new one-input to one-output control scheme [3] and permits for a new, near limitless interaction on a two dimensional plane [7]. New and potential variables of finger length, width, direction of stroke, number of strokes, character structures, and even posture can now influence gesture performance [1, 2]. Additionally, in contrast to smaller touch screens, larger formats are no longer constrained with index finger versus thumb selection or limited screen real estate [12]. Further, developing specific gesture sets for multi-touch devices has come to receive considerable attention [5, 6]. Researchers have developed various methods for determining gesture sets, ranging from researcher-defined sets [15] to user-defined sets [11, 14]. However, there is currently no commonly accepted set of multi-touch gestures [13].

Around the same time, a separate study focused on brief interactions with a multi-touch interface and used a combination of 81 user and researcher defined gestures to achieve 22 common commands (e.g. cut, paste, drag) on a tabletop surface [9]. Results supported that participants preferred physically and conceptually simple gestures. An earlier finding [8] also highlighted straightforward gestures such as a tap followed by a lasso, were the most common multi-touch user controls.

Working with the multi-touch system at the War College, the developer observed that the orientation of the platform seemed to affect the approach of students. Based on MTMU work and observations of emergent behavior, or unintentional or surprising combinations of War Gaming Department student actions [7], the developer hypothesized that orientation may affect gesture preference. To investigate this hypothesis, the present study expanded previous research [9] to better determine how varying orientation affects gesture preferences on multi-touch systems.

The SPAWAR study examined user preferences for command gestures on large multi-touch devices in horizontal and vertical orientations. A previous study presented gesture preferences for 22 commands using a Microsoft Surface (Redmond, WA) multi-touch device [9]. That study compared the differences between user and researcher generated gestures, but only presented results for a horizontal device. The SPAWAR study attempted to replicate the previous study with the addition of an orientation manipulation to include both horizontal and vertical MTMU devices. In the present paper, commands are listed in italics, while gestures are listed in single quotations.

2 Method

The gesture set used for this study was based on previous work [9], which developed 63 distinct gestures using 22 commands from human computer interaction (HCI) researchers and users [14]. Some overlap of gestures (e.g. 'Drag' was used for both *Move* and *Minimize* commands) led to 81 total gestures evaluated using 22 commands. In order to compare the results of the current study with the previous study, no gestures were added or removed from the set.

Participants. Forty employees from SPAWARSYSCEN Atlantic in Charleston, SC participated. While handedness and previous experience with touch screen devices were not controlled, both were recorded to ensure that groups were similar. Twenty-one participants were tested in the vertical orientation and 19 were tested in the horizontal orientation.

Demographics. Participants self-reported 77.5 % right handed, 15 % left handed, and 7.5 % ambidextrous, and were evenly distributed between horizontal and vertical devices. Twenty-seven point 5 % of participants indicated no experience with multi-touch devices prior to this experiment while the remaining 72.5 % averaged 8.94 h (s = 9.03 h) usage per week. See Fig. 1 for the multi-touch use sorted by age distribution of participants.

Materials. Two identical Perceptive Pixel, Inc. (PPI) touch screens were used for the SPAWAR study. Each screen was 48 × 27 in (55 in. diagonally) and had a resolution of 1900 × 1200 pixels. The base of the horizontal screen was 38 inches above the ground. The bottom of the vertical surface was 42 in. above the ground. Improving on previous multi-touch technology, the PPI technology in the present study uses a layer of film that interfaces with the sensor via a technique called frustrated total internal reflection (FTIR) [4, 9, 14]. This higher quality sensing mechanism reduces the engineering effort, doesn't require bare skin contact and can support a very large number of touch points.

A program was created to mock-up videos of the researchers performing the gestures. A second program displayed the videos of each gesture grouped by

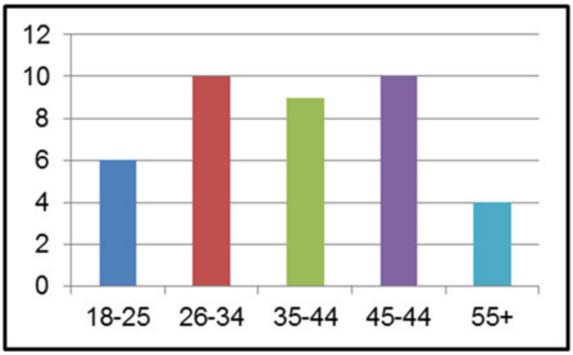


Fig. 1 Participant hours of multi-touch use per week by age

command. Order of commands and gestures for each command were randomized for each participant.

Procedure. The current procedure was adapted from previous work [9]. Participants completed an informed consent and filled out a brief demographic questionnaire yielding age and height information, as well as touch screen usage. The researcher then presented participants with a brief overview of the study.

Participants were asked to read a short definition of a command (i.e. *Accept*). They then viewed a short video of a researcher performing a gesture associated with the command. For the practice command—*Accept*—participants observed a video of the gesture with the title ‘Draw Check’ of the researcher making a checkmark motion using their index finger. Participants were encouraged to watch the video more than once if necessary. They were then asked to practice the gesture while touching the device, without leaning against it. Once comfortable with the command, the researcher asked them to rate the goodness of fit of the gesture to the command and the ease of performing the gesture on a 7-point Likert scale. Participants repeated this process (steps 1–5) for each gesture associated with a command. Once all gestures associated with a given command had been rated for ease and fit, participants viewed a screen containing videos of all gestures for the command in a repeat loop and were asked to select which gesture they felt best represented the command (see Fig. 2). Participants were also queried for additional free form ideas regarding the gestures. Once participants demonstrated understanding of the procedure, commands were chosen randomly.

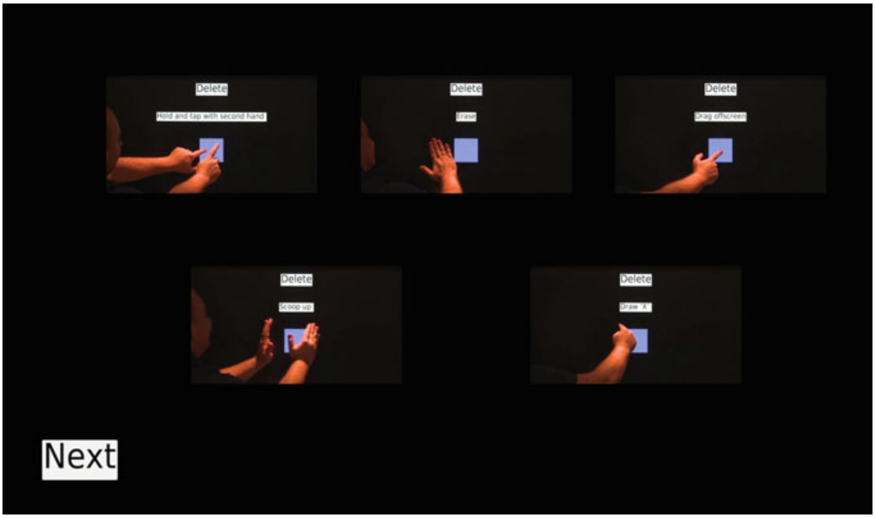


Fig. 2 All gestures associated with the *Delete* command

3 Results

Participant agreement on best gesture varied across commands. Preferences by study and device orientation can be seen in Table 1. The numbers in each column are the percentage of participants who preferred the winning gesture (M = [9]; H = horizontal orientation; V = vertical orientation). If more than one gesture is listed in a column for a particular command, the two gestures tied. Differences in

Table 1 Comparison of previous work (M) results [9] with horizontal (H) and vertical (V) preferences from the current study

Command	Gesture	M	H	V
Accept	Draw check	100	100	100
Cut	Slash	77.3	57.1	63
Delete	Draw ‘X’	63.6	42.9	53
	Drag offscreen		42.9	
Duplicate	Pull right finger from left	36.4		52
	Tap source then destination		47.6	
Enlarge	Reverse pinch	45.5	57.1	
	Pull apart with fingers			58
Help	Draw ‘?’	86.4	90.5	100
Menu	Tap and hold	54.5	61.9	37
Minimize	Drag to bottom of display	90.9	61.9	74
Move	Drag	81.8	76.2	84
Next	Draw line left to right	86.4	71.4	74
Open	Double tap	86.4	90.5	95
Pan	Drag whole hand	63.6		
	Drag four fingers		95.2	79
Paste	Drag	54.5	42.9	42
Previous	Draw line right to left	90.9	71.4	74
Reject	Draw ‘X’	54.5	38.1	
	Drag offscreen		38.1	
	Slash			53
Rotate	Drag corner	68.2	90.5	53
Select group	Hold and tap	59.1	38.1	
	Tap			42
Select single	Tap	81.8	76.2	84
Shrink	Pinch	68.2	61.9	42
Undo	Draw ‘U’	63.6		
	Scratch out		33.3	32
Zoom in	Reverse pinch	45	57.1	
	Pull apart with fingers			42
Zoom out	Pinch	22.7	52.4	
	Move index fingers together			42

the data set between previous work [9] and the current study are in bold font, however this does not indicate statistical significance.

Gesture Preference. A Fisher's Exact Test on the distribution of preferences for each command revealed significant differences in orientation for Duplicate, Enlarge and Rotate. As an example of this, participants using the vertical device prefer a two-handed zoom gesture, while participants using the horizontal device preferred a one-handed gesture.

Fit and Ease of Use. Overall, there was a correlation between participant ratings of gesture Goodness of Fit for the command and Ease of Use of the gesture. The Pearson correlation between the two variables across all gestures was $r (N - 2) = 0.547$ ($p < 0.01$). Means and standard deviations of the two measures were similar for all gestures for Goodness of Fit ($M = 5.38$, $SD = 1.7$) and Ease of Use ($M = 5.48$, $SD = 1.54$).

Pairwise Kruskal-Wallis tests for both Goodness of Fit and Ease of Use revealed that both had higher ratings for the vertical group compared to the horizontal group. For Goodness of Fit, participants in the vertical group ($M = 5.44$) rated the Goodness of Fit significantly higher than those in the horizontal group ($M = 5.31$) ($H = 5.883$, 1 DoF, $p = 0.015$). Similarly, for Ease of Use, participants in the vertical group ($M = 5.61$) felt that the gesture ease of performance was greater than those in the horizontal group ($M = 5.37$) ($H = 25.158$, 1 DoF, $p \approx 0$).

Focusing on the horizontal and vertical device orientations individually, there were strong significant correlations between participant ratings of gesture Goodness of Fit and Ease of Use. For the horizontal orientation, the Pearson correlation between the two variables across all gestures was 0.593 ($p < 0.01$). Means and standard deviations of the two measures were similar for all gestures (Goodness of Fit $M = 5.31$, $SD = 1.7$; Ease of Use $M = 5.37$, $SD = 1.54$). For the vertical orientation, the Pearson correlation between the two variables across all gestures was 0.493 ($p < 0.01$). Means and standard deviations of the two measures were again similar for all gestures (Goodness of Fit $M = 5.44$, $SD = 1.68$; Ease of Performing $M = 5.61$, $SD = 1.52$).

Pairwise Kruskal-Wallis tests were also completed for the vertical and horizontal orientations for fit and ease of use for each gesture. Table 2 lists the command and gesture where there was a significant difference between the means of the Goodness of Fit or Ease of Use Likert scale measures. The value in the fit or ease column indicates which orientation was easier or a better fit. Future analysis will be required to identify if gesture preference differs depending on whether a gesture requires one or two hands.

Table 2 Commands and gestures with significant differences in fit and/or ease

Command	Gesture	Fit	Ease
Delete	Drag offscreen		H
Menu	Open hands like a book	V	
Move	Drag	H	H
Pan	Drag four fingers		V
Rotate	Drag corner in circular motion		H
Rotate	Twisting grasp		V

4 Conclusion

Results confirm that orientation was a factor in gesture preference for a limited set of commands in this study. At a minimum, designers should consider utilizing different gesture sets depending on the orientation of the device. Perhaps a better solution would be to include redundancy within the gesture set to include the top gestures for each orientation. Further analysis is required to identify exactly what leads to the differences identified in this study, with respect to wrist angle, viewing angle, number of hands, number of fingers, etc.

Touch screen usage was not controlled as the applications utilized for touch screen devices would be for experienced users. While it's important to ensure that the gestures are intuitive enough for someone with little or no experience to understand and execute them, the majority of users were expected to have some previous exposure to touch screens.

The previous study only used right-handed participants. Similar to the above argument, the research team chose against controlling for handedness because both right- and left-handed users needed to be able to execute the same commands. Left-handed users almost always executed the gestures using their right hands and none of the participants mentioned an issue of handedness. Wrist angle may be a significant factor explaining these results and is a potential focus for future research.

5 Application

Results of this research will inform the development of SPAWARSYSCEN Atlantic multi-touch devices. The intent was to contribute to the ease of use of future multi-touch devices. Simplicity and usability are notable concerns for the War Gaming Department, a customer for SPAWARSYSCEN Atlantic. Any improvement in ease of learning results in a corresponding increase in game playing time, in addition to a significant enhancement of the game experience where multi-touch technologies are involved. This research should contribute to the overall body of knowledge for the evolving field of multi-touch development. Specifically, it should be possible to use this research to create a set of guidelines for development of multi-touch applications. Many developers still think in terms of a single interface point of interaction. Multi-touch is often limited to pinch and zoom, but the potential for more sophisticated gesture sets that can capture parallel interactions is unlimited.

Future research should focus on gesture preferences for more applied systems. There are many considerations for identifying the proper gesture set for multi-touch applications. While it is important to understand user gesture preferences for basic commands, it is also necessary to ensure that the same commands are preferred during actual use. There are several practical considerations that need to be considered in the development of an accepted set of multi-touch development guidelines. Multi-touch technology implementations are a factor limiting the gesture set. Not every technology can see a short distance beyond the edge of the touch screen or measure the amount of pressure for each touch gesture. In addition, some gestures might collide with others; for example, an "X" gesture and the slash gesture can overlap. How can the application decide which gesture has been executed, particularly where multiple people may be touching the screen at any given time?

It may also be that the current gesture set is lacking gesture options for some commands. For example, the *Pan* command had two associated gestures, using four fingers to pan across a scene or using the whole hand. Some participants indicated that they would prefer to use only one finger to pan over the two options presented. Other modalities could be used and included as a combination within the gesture set. One example for this might include a pressure based motion ('push pin') followed by a 'drag to.' The team would also like to begin applying its experience in multi-touch development to create applications for the control of multiple small robots.

References

1. Chen, Z., Rau, P.L.P., Chen, C.: The effects of human finger and chinese character on chinese handwriting performance on mobile touch devices. Hum. Factors: J. Hum. Factors Erg. Soc. **56**(3), 553–568 (2013)
2. Chourasia, A.O., Wiegmann, D.A., Chen, K.B., Irwin, C.B., Sesto, M.E.: Effect of sitting or standing on touch screen performance and touch characteristics. J. Hum. Factors Erg. Soc. **55** (4), 789–802 (2013)
3. Courtemanche, A., Micire, M., Yanco, H.: Human-robot interaction using a multi-touch display. 2nd IEEE Tabletop Workshop (2007)
4. Han, J.Y.: Low-cost multi-touch sensing through frustrated total internal reflection. In: Proceedings of 18th Annual ACM Symposium on User Interface Software and Technology, pp. 115–118 (2005)
5. Hinrichs, U., Carpendale, S.:. Gestures in the wild: studying multi-touch gesture sequences on interactive tabletop exhibits. In: Proceedings of SIGCHI Conference on Human Factors in Computing Systems, pp. 3023–3032 (2011)
6. Kammer, D., Wojdziak, J., Keck, M., Groh, R., Taranko, S.: Towards a formalization of multi-touch gestures. In: ACM International Conference on Interactive Tabletops and Surfaces, pp. 49–58 (2010)
7. Micire, M., Drury, J.L., Keyes, B., Yanco, H.A., Courtemanche, A.: Performance of Multi-touch Table Interaction and Physically Situated Robot Agents. ACM, New York (2007)
8. Micire, M., Desai, M., Courtemanche, A., Tsui, K.M., Yanco, H.A.: Analysis of natural gestures for controlling robot teams on multi-touch tabletop surfaces. In: Proceedings of ACM International Conference on Interactive Tabletops and Surfaces, pp. 41–48. ACM, New York (2009)
9. Morris, M.R., Wobbrock, J.O., Wilson, A.D.: Understanding users' preferences for surface gestures. In: Proceedings of Graphics Interface, pp. 261–268. Canadian Info. Proceeding Society (2010)

10. North, C., Dwyer, T., Lee, B., Fisher, D., Isenberg, P., Robertson, G., Inkpen, K. (2009). Understanding Multi-touch Manipulation for Surface Computing. Human-Computer Interaction, pp. 236–249. Springer, Berlin (2009)
11. Ruiz, J., Li, Y., Lank, E.: User-defined motion gestures for mobile interaction. In: Proceedings of SIGCHI Conference on Human Factors in Computing Systems, pp. 197–206. ACM, New York (2011)
12. Trudeau, M.B., Udtamadilok, T., Karlson, A.K., Dennerlein, J.T.: Thumb motor performance varies by movement orientation, direction, and device size during single-handed mobile phone use. J. Hum. Factors Erg. Soc. **54**(1), 52–59 (2012)
13. Urakami, J.: Developing and testing a human-based gesture vocabulary for tabletop systems. J. Hum. Factors Erg. Soc. **54**(4), 636–653 (2012)
14. Wobbrock, J.O., Morris, M.R., Wilson, A.D.: User-defined gestures for surface computing. In: Proceedings of the SIGCHI Conference on Human Factors in Computing Systems, pp. 1083–1092. ACM, New York (2009)
15. Wu, M., Balakrishnan, R.: Multi-finger and whole hand gestural interaction techniques for multi-user tabletop displays. In: Proceedings of 16th Annual ACM Symposium on User Interface Software and Technology, pp. 193–202. ACM, New York (2003)

Ergonomic Evaluation of Refrigerating Chamber Volume of Refrigerator

Huimin Hu, Ling Luo, Aixian Li, Linghua Ran, Hong Luo, Xin Zhang and Chaoyi Zhao

Abstract Due to the mismatch between the human body dimension and the refrigerator's structure, many household refrigerators' volumes don't get fully utilized. Using the ergonomic design principle-based approach, 6 model machines of 6 brands purchased from household appliance markets at random were evaluated in separating sides, which were the Available Volume base on the normal reach zone and Easy-to-Use Volume base on the comfortable reach zone. This evaluation aims to promote the available and easy-to-use volume of household refrigerators by ergonomic design approach.

Keywords Ergonomics evaluation · Available volume · Easy-to-use volume · Refrigerator · Normal reach zone · Comfortable reach zone

---

H. Hu (✉) · L. Luo · A. Li · L. Ran · H. Luo · X. Zhang · C. Zhao
Ergonomics Laboratory, China National Institute of Standardization,
No. 4 Zhichun Road, Haidian District, Beijing, China
e-mail: huhm@cnis.gov.cn

L. Luo
e-mail: 315794507@qq.com

A. Li
e-mail: liax@cnis.gov.cn

L. Ran
e-mail: ranlh@cnis.gov.cn

H. Luo
e-mail: luohong@cnis.gov.cn

X. Zhang
e-mail: zhangx@cnis.gov.cn

C. Zhao
e-mail: zhaochy@cnis.gov.cn

M. Soares et al. (eds.), *Advances in Ergonomics Modeling, Usability & Special Populations*, Advances in Intelligent Systems and Computing 486,
DOI 10.1007/978-3-319-41685-4_33

1 Introduction

Volume is an important performance index of household refrigerators. Investigation indicates that consumers pay great attention to volume of refrigerating chamber when purchasing refrigerators. In recent years, big volume has also become a development direction in the refrigerator industry. Sales of large-sized and large-volume refrigerators in the market have increased steadily. Large-volume refrigerators are suitable for families with many members. Large volume not only satisfies big families' demand for food storage but also fulfills different people's demand for individualized freshness preservation. Therefore, large-volume refrigerators are popular among consumers.

However, ergonomic tests and surveys of consumers' using habits to the structure of refrigerator have found out that a relatively outstanding problem exists in large-volume refrigerators: Many large-sized and large-volume refrigerators (especially refrigerators of some foreign brands) are not matched with Chinese consumers' body size. The height of shelf and partition at the upper layer are obviously higher than the reachable height of upper limbs of consumers. Many consumers feedback that there are many places in the refrigerator "beyond their reach", "it is not convenient to pick and place articles", and "the utilization rate of many spaces in the refrigerator is very low due to inconvenience of reach". These fancy refrigerators are especially unsuitable for users who are mainly housewives or the elderly. Most refrigerators' effective volume is smaller than their nominal volume in the market [1, 2]. Although the spaces of refrigerator are designed very big, body size and using habits of users are not considered during structural design and consequently the consumers cannot conveniently use refrigerator storage spaces which are too high or too deep. As a result, the utilization rate of volume is lowered and the spaces are wasted. Besides, consumers' using experience and satisfaction are also compromised.

On the basis of the current situation mentioned above, in order to get to know the current actual design conditions of refrigerator volume in the market, this ergonomic evaluation activity targeted at refrigerator volume has been launched. This evaluation is mainly based on Chinese people's physiological size and using habits. Based on ergonomic principle and method [3] and centering on provision of conveniences for users as basic principle and tenet, a survey is launched to see if the refrigerating chamber volume of three-door refrigerators in Chinese market can be conveniently, effectively and fully used by the consumers.

2 Evaluation Products

During this evaluation, refrigerators of 6 mainstream brands with high market sales and equivalent functions in recent period are selected as evaluated model machines (see Table 1). The sampling process fully simulates consumers' actual purchasing behaviors. 6 model machines of 6 brands are purchased from household appliance markets at random to evaluate the usability of refrigerating chambers of these model machines.

Table 1 Model machines of 6 types of refrigerator evaluated this time

Evaluated model machine	Refrigeration volume (L) (nominal volume of product)	Energy efficiency level	Overall dimensions (mm)
Model machine 1	167	1	629 * 650 * 1855
Model machine 2	163	1	640 * 655 * 1804
Model machine 3	177	1	606 * 639 * 1900
Model machine 4	157	1	750 * 715 * 2050
Model machine 5	187	1	600 * 663 * 1860
Model machine 6	234	1	590 * 664 * 1868

3 Evaluation Contents and Indexes

The contents of this evaluation include "available volume" and "easy-to-use volume". This survey were mainly based on these two contents. The specific definitions of these two contents and evaluation indexes are shown as Table 2.

Table 2 Ergonomics evaluation contents and indexes

Evaluation contents	Definition	Evaluation indexes	Definition
Available volume	The refrigerating chamber volume of refrigerator within "normal reach zone" of upper limbs (with hand grasping center as benchmark) when the users use the refrigerator according to the natural article picking and placing habits	Normal reach zone	The special scale determined when body remains still with shoulder joint as center of circle and distance from shoulder joint to front end of palm upon hand grasping of article as radius is the normal reach zone (as shown in Fig. 1). This scope indicates the maximum reach of article picking and placing by arm when a person does not bend down or twist the body
Easy-to-use volume	The refrigerating chamber volume of refrigerator within "comfortable reach zone" of upper limbs (with hand grasping center as benchmark) when the users use the refrigerator according to the natural article picking and placing habits	Comfortable reach zone	The research indicates that the user's comfortable boundary is where the shoulder level is lifted by an angle of 20° [4]. When the angle exceeds 20°, the user will feel uncomfortable. Therefore, 20° is determined as users' optimal comfortable operation angle, and the spatial scale with angle below 20° is determined as comfortable reach zone (as shown in Fig. 1). This scope indicates the reach zone at comfortable lifting height when the user lifts arm upward to pick and place articles

4 Evaluation Method

4.1 Evaluation Criterion

The appearance and size of most popular foreign-brand refrigerators in the market are generally tall, large and wide. These refrigerators are designed with foreigner's body size as reference. Therefore, for relatively short Chinese people, mismatch between products and consumers' body size will be caused such as "beyond one's reach" or "difficult to pick and place" when they are using these refrigerators. Therefore, the size design of refrigerator products shall be based on Chinese people's body measuring data. For example, the design of refrigerator size including cavity depth of refrigerator, height of layer partition, height of door shelf and size and height of doorknob shall fully consider Chinese people's height, arm length, hand size, range of activity of upper limbs and reach zone in order to make the refrigerators designed practical and easy to use. On the basis of the abovementioned analysis, since the main refrigerator users of China are females, the evaluation criterion is based on the human measuring data of 50-percentile adult females of China (equivalent to average height of Chinese adult females) [5, 6].

4.2 Test Method

One of the most important rule to design friendly use product is following the upper reach zone of the proper human body. Many researchers such as Yang [5] studied the upper extremity comfort ROM of ergonomic methods for household products design, and Porter and Gyi [7] using the human body's reach zone to evaluate and design the driving comfortable of cars. Human ergonomic simulated analysis system (JACK) is adopted in this evaluation. This system can construct the cavity of evaluated refrigerator and give the reach zone of human size. Also, it can directly evaluate if the body of refrigerator is within reach zone of target users.

In this evaluation, the human measuring data of 50-percentile adult females of China is used as basis (the data source is Chinese Adult Human Body Size Database of China National Institute of Standardization). "Normal reach zone" and "comfortable reach zone" are used as evaluation indexes. Human ergonomic simulated analysis method is utilized to measure and evaluate "available volume" and "easy-to-use volume" of refrigerating chamber of 6 three-door refrigerators with the purpose of getting to know the ergonomic design conditions of refrigerator volume in the market and providing reference for their ergonomic design (Fig. 2).

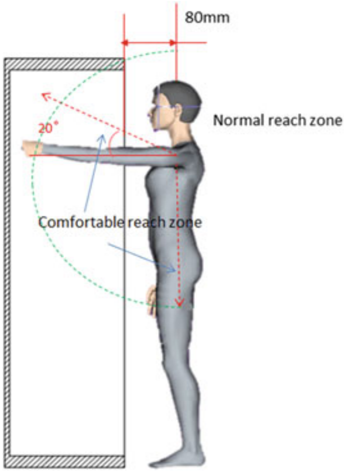


Fig. 1 Normal reach zone and comfortable reach zone. *Note* It is found out in the survey that the distance between centers of shoulder joint and front end of refrigerating chamber of refrigerator is about 80 mm

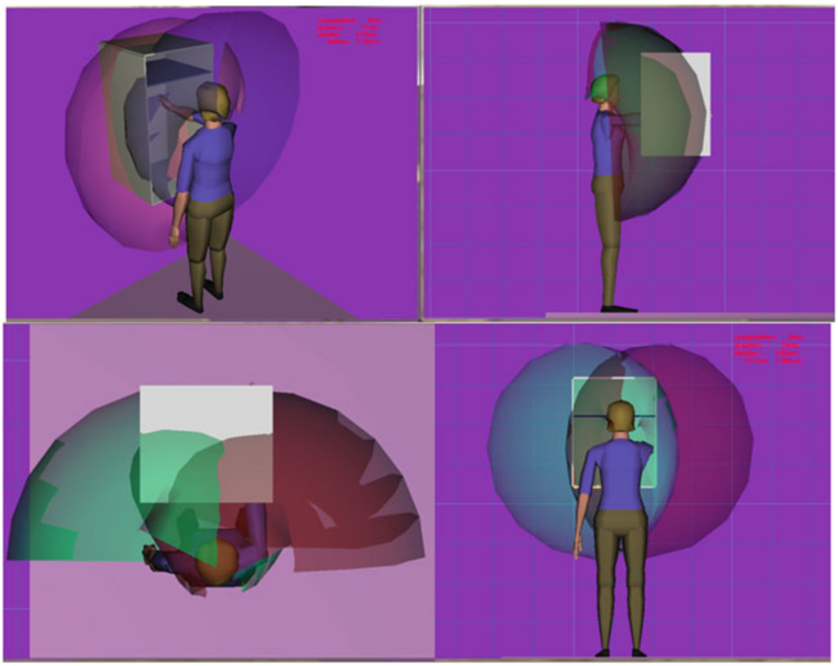


Fig. 2 Ergonomics evaluation of reach zone in Jack

5 Evaluation Results

On the basis of the abovementioned evaluation principle and method, the evaluation results acquired this time are shown in Table 3, Figs. 3 and 4. We can see from the results indicated in Table 3 that the volume of refrigerating chamber of these 6 types of refrigerator fails to realize 100 % of availability rate. The evaluation results of available volume and easy-to-use volume are shown as follows respectively:

(1) Available Volume

We can see from Table 3 and Fig. 3 that there is nearly 10–15 % of space in the refrigerating chamber volume of these 6 types of refrigerator involved in evaluation "beyond reach zone" especially for model machine 4 which has minimum available volume. About 15 % of space of model machine 4 cannot be normally reached by users and thus spatial waste is caused.

(2) Easy-to-use Volume

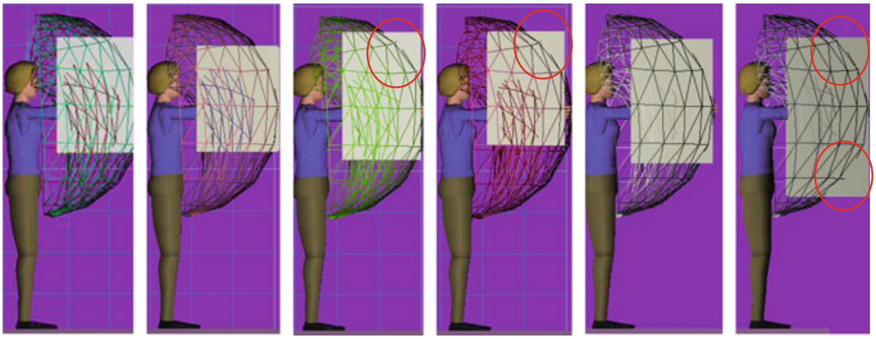
We can see from the easy-to-use rate of volume of these 6 evaluated refrigerators (Table 3; Fig. 4) that only 40–60 % of space of refrigerating chamber of the refrigerators is comfortable and easy to use. In other words, there is about half of space of refrigerating chamber of most refrigerators not conveniently used by users.

Table 3 Evaluation results of available volume and easy-to-use volume of model machines of 6 types of refrigerator

	Model machine 1	Model machine 2	Model machine 3	Model machine 4	Model machine 5	Model machine 6
Cavity volume of refrigerating chamber (L)	166.26	151.59	178.17	161.48	178.62	232.91
Available volume (L)	143.29	139.82	156.96	137.80	165.34	204.04
Easy-to-use volume (L)	70.80	70.06	76.76	56.92	89.96	128.18
Availability rate (%)	86.18	92.23	88.10	85.33	92.57	87.60
Easy-to-use rate (%)	54.76	59.40	54.30	47.62	61.66	63.66

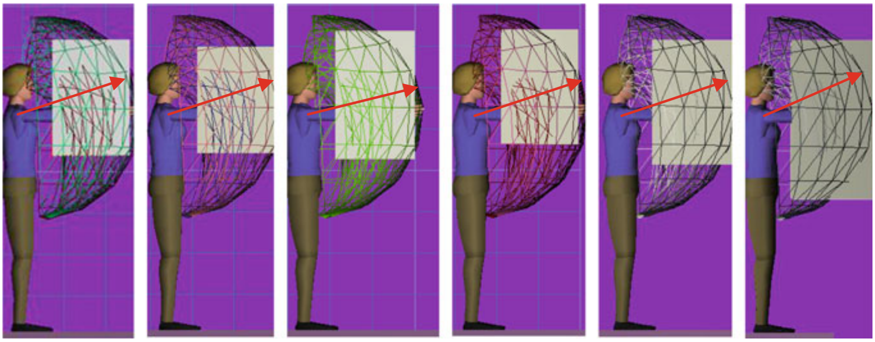
Notes

1. The cavity volume of refrigerating chamber refers to volume of refrigerating chamber of refrigerator not including door shelf measured according to GB/T 8059. This evaluation only involves cavity of refrigerating chamber of refrigerator
2. Availability rate refers to ratio between available volume of cavity of refrigerating chamber of refrigerator and measured volume in standard GB/T 8059
3. Easy-to-use rate refers to ratio between easy-to-use volume of cavity of refrigerating chamber of refrigerator and measured volume in standard GB/T 8059



Model machine 1 | Model machine 2 | Model machine 3 | Model machine 4 | Model machine 5 | Model machine 6

Fig. 3 Normal reach zone of refrigerating chambers of 6 types of refrigerator



Model machine 1 | Model machine 2 | Model machine 3 | Model machine 4 | Model machine 5 | Model machine 6

Fig. 4 Comfortable reach zone of refrigerating chambers of 6 types of refrigerator

We can see from the results summarized above that there is still a big space to improve especially easy-to-use volume during ergonomic design.

We can directly see from Fig. 3 that the refrigerating chamber of all three-door model machines involved in evaluation is not completely within the normal reach zone of 50-percentile females especially for model machine 6. Since the size of refrigerating chamber of model machine 6 is relatively big, the condition of "beyond reach zone" occurs in both upper and lower parts of refrigerating chamber. As for model machine 1 and model machine 4, since the refrigerating chamber is relatively high, relatively big area "beyond reach zone" occurs in the upper part. We can also see from Fig. 3 that the unavailable volume of model machine 1, model machine 4 and model machine 6 (all of them are foreign-brand refrigerators) is relatively big.

We can see from Table 2 and Fig. 4 that there is nearly 40–50 % of volume of all model machines involved in evaluation not easy to reach especially for model machine 1 and model machine 4 (both are foreign-brand refrigerators). Since the refrigerating chamber is relatively high, users need to lift their arms higher or "tiptoe" when using the upper part of refrigerators. For model machine 6, since the refrigerating chamber is relatively low, users would "bend" when using this refrigerator. As a result, the easy-to-use rate of this model machine is not high as well.

It is found out during research on cavity of refrigerating chamber of model machines involved in evaluation that the layer partitions of model machine 2 and model machine 4 are not adjustable, while adjustable slots are set up in all other model machines. The survey indicates that setting of adjustable layer partitions in refrigerating chamber cannot only adopt to the using requirements of people with different heights but also improve article storage space given same size. The effective usable volume is superior to that of refrigerating chamber when the layer partitions are not adjustable. Therefore, in order to effectively improve available volume and easy-to-use volume in refrigerating chamber of refrigerators, the cavity of refrigerating chamber cannot be simply designed within reach zone of Chinese people's human body. Human-oriented design of internal structure of refrigerator shall also be implemented to improve consumers' use comfort and enjoyment.

6 Conclusion and Prospect

It is found out in this evaluation that refrigerators with relatively low availability rate and easy-to-use rate of refrigerating chamber volume are all foreign-brand refrigerators. Compared with other refrigerators with relatively good volume design, the advantage of "large volume" of these refrigerators is not obvious since their size are not matched with Chinese consumers' body size. Besides, these refrigerators also cause inconveniences while using. Therefore, they lost the original purpose and meaning of the design.

This evaluation reminds us that the design concept of human ergonomics shall be fully integrated during structural design of refrigerator in order to design usable and easy-to-use refrigerators and fully reflect human orientation and satisfaction of refrigerator design. As for human-oriented refrigerators complying with ergonomic design concept, not only functional features and structural characteristics but also consumers' physical features and using habits shall be considered to ensure convenience and comfort of actual users and bring easiness and convenience to people's lives.

Acknowledgments This research is supported by the National Key Technology R&D Program: control devices ergonomics design technology and standards research (project number 2014BAK01B02).

References

1. Ren, Z.: Refrigerator's effective volume smaller that their nominal rates. China Consum. J. 2011 (A03)
2. Refrigerator's effective volume should be improved. China Consum. J. **8**, 37–37 (2011)
3. Sanders, M.S., Mc Cormick, E.J.: Human Factors in Engineering and Design, pp. 424–512. McGraw Hill, New York (1993)
4. GB/T 1000-1988. Human dimensions of Chinese adults
5. Yang, F., Zhou, Q., Yang, A., et al.: Based on upper extremity comfort ROM of ergonomic methods for household products design. Digital human modeling. Applications in health, safety, ergonomics and risk management, pp. 167–173. Springer International Publishing (2014)
6. National Center for Biotechnology Information. http://www.ncbi.nlm.nih.gov
7. Porter, J.M., Gyi, D.E.: Exploring the optimum posture for driving comfort. Int. J. Veh. Des. **19** (3), 255–266 (1998)

Managing Variations in Process Control: An Overview of Sources and Degradation Methods

Beata Mrugalska and Tareq Ahram

Abstract Understanding variation is a crucial aspect of managing and improving any manufacturing or product development process. This paper investigates sources of variations in process control. It shows main sources of variability such as actual process variations or measurement variations. Moreover, it attempt to classify causes of variation. Based on state-of-the-art research methods, researchers are able to investigate variability and develop a process to minimize the negative impact of variability on processes. In particular attention is the role of human factors and its diverse impact on process control.

Keywords Process control · Process variation · Lean thinking · Statistical process control · Measurement variation

1 Introduction

In the last few decades, the number of new product introductions has increased dramatically. However, the cruel reality is that the majority of them have never launched to the market and most faced failure. In an increasing competitive environment, for a product to be successful it requires excellence along its entire development process [1, 2]. Product development should rely on customer-driven design, which is the thoughtful examination starting from its outmost periphery to the core. However, in practice it is still sometimes a challenge for the producers to provide quality performance, reliability and maintainability which can lead to longer product

B. Mrugalska (✉)
Poznan University of Technology Faculty of Engineering Management,
ul. Strzelecka 11, 60-965 Poznan, Poland
e-mail: beata.mrugalska@put.poznan.pl

T. Ahram
Institute for Advanced Systems Engineering, University of Central Florida,
Orlando, USA
e-mail: tahram@ucf.edu

M. Soares et al. (eds.), *Advances in Ergonomics Modeling, Usability & Special Populations*, Advances in Intelligent Systems and Computing 486,
DOI 10.1007/978-3-319-41685-4_34

lifespan, shorter lead times, lower development and warranty costs, and lesser scraps and reworks [3, 4]. Implementing such framework creates the need for controlling process variations. In most cases they derive from single variables influencing the process such as machine or tool wear, material properties and work environment [5].

In this paper researchers focus on the role and impacts of human factors on different stages of product life-cycle development and its influence on variations. In order to assess different sources of process variations, methods allowing for their degradation are presented. Particularly, attention is paid to measurement of variations. It is revealed that the emphasis on lean thinking as the behavior and performance of human is not amendable to any mathematical analyses and forecasting. Human capabilities are not uniform and particularly visible in reference to human performance and the interface with technology. On the other hand, the causes and Subcauses of measurement variations can be identified which will allow categorizing variability in five main categories, which are: standard, workplace, instrumentation, operator and environment.

2 Process Control

A process is broadly defined as an adjustment or alteration of raw material into a final product with the application of labor, instruments, and facilities in accordance with customer requirements [6]. Generally, it consists of input and output variables but only some of those variables are chosen to control the process. The inputs, which are under control, are manipulating variables, and uncontrolled variables are disturbances. On the other hand, the outputs are divided into measured and unmeasured variables and their feedback is compared with the desired set of values (see Fig. 1).

In order to control the operation of the process, it is required to measure process outputs or disturbance inputs to adjust inputs in such manner that the proper values are obtained [7]. If it is possible to achieve such adjustments, then the process can be perceived as consistent and predictable. Regardless of the process, process-control consists of formulating or defining:

- objectives of control,
- control structure,
- control algorithm,
- corrective action to minimize the variances,
- improvements,
- conformance to the desired set values.

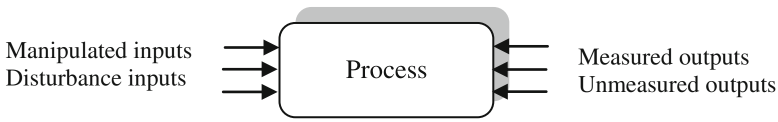


Fig. 1 Process representation

The control of an operating unit is generally perceived as the control of each operation separately, even if there are multiple, sometimes conflicting objectives of the unit operation [8]. Control structure encompasses input and output variables, constraints, operating characteristics, safety, environmental and economic considerations and control structure. It can be a feed forward or feedback. In the first type the disturbance variable is measured and on its basis the manipulated variable is adjusted, whereas in the second one control system measures the output variable, which is compared with the assumed output value to adjust the manipulated variable appropriately [9]. Moreover, the control algorithm is a mathematical representation of relations between the measured output variable values and the manipulated input variable [10]. It allows monitoring all operations involved in the process, and undertaking corrective actions and improvements to ensure safe operations, a high-quality product and profit. The output conformance to the desired technical-design specifications is primarily concerned with process variations and ability to control its causes. Incorrectly rejected products or acceptance of faulty products is either costly or negatively effecting company's product reputation [11].

3 Process Variation

Process variation is inevitable in any manufacturing process. If it is unintended it can negatively influence process performance, customer satisfaction [12]. Process variation can be resulted from two distinct sources: actual process variation and measurement variation (Fig. 2).

Such a categorization of process variability allows to distinguish major root causes of process variation and develop solution for improvement [14].

3.1 Actual Process Variation

Actual process variations can be divided into two sources: common and special causes. Common cause variations affect the design of product and production

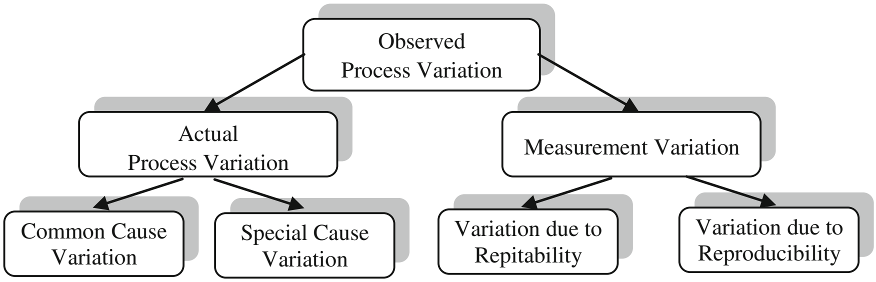


Fig. 2 Analysis of process variations (adapted from [13, 14])

system. They derive from the primary elements of the system in which the process operates. Generally, they can be differentiated into materials, equipment, people, environment and methods, and can be declined due to redesign of the product, appliance of better technology or training. For a process, in which only common variations appear, it is perceived as systematic and in control. Moreover, it is described as:

- repeatable,
- stable,
- consistent,
- predictable.

Such situation characterizes a process performance replicated time after time. On the other hand, special variations are not the component of the designed system and result from unexpected change which appears in one or more parts of the system [15]. Such process is out of control and it can be described as:

- changing,
- unstable,
- unpredictable.

Previous research shows that common causes account for 80–95 % of all noticed variations in the output of production process. The remaining variations show off as an unexpected change in the process output and their sources can be found in external factors, not inherent in the process [16].

3.2 Measurement System Variation

Measurement system variation concerns all variations which are identified during a measurement process. Any component of a measurement system can contribute to source of variation (i.e. gages, standards, procedures, software, environmental components). In particularly, it is the sum of variations resulting from repeatability and reproducibility [17]. Repeatability is defined as variation in measurements resulting from the measuring device, or die variation, noticed when the same operator measures the identical characteristic on the same part again and again with the same device. On the other hand, reproducibility encompasses variation due to the measuring system, or the variation which is perceived when various appraisers measure the same characteristic of the component using the same device [18, 19]. Therefore, in order to estimate repeatability, each appraiser must conduct the measurement of each part at least twice, whereas, to estimate reproducibility, there is a need to engage at least two operators in the measurement process. Furthermore, the random order of measurement of parts and the possible range of measurements must be ensured. The degree of repeatability and reproducibility show the precision of the measurement instrument [20].

Table 1 Measurement system variability—its categories and causes (adopted from [19])

Category	Cause	1st subcause	2nd subcause
Standard	Traceability Stability Geometric compatibility	Calibration Coefficient of thermal expansion Elastic properties	
Workpiece (part)	Operational definition Adequate datums Cleanliness Interrelated characteristics Elastic deformation Hidden geometry	Mass Elastic properties Supporting features	
Instrument (gage)	Design Build Maintenance	Use assumptions Robustness Bias Amplification Contact geometry Deformation effects Variability Build tolerances Build variation Design validation Calibration	Stability Linearity Sensitivity Consistency Uniformity Repeatability Reproducibility Clamping Locators Measurement points Measurement probes
Person (appraiser)	Skill Understanding Limitations Procedures Attitude	Experience Ability Training Experience Training Educational Psychophysical Social Operational definition Visual standards Background Experience	
Environment	Workstation organization Rhythm and pace Air pollution Lighting Vibration Noise Temperature	Cycles Standard vs ambient Thermal expansion	

In the ideal measurement system there should be statistically zero mistakes in reference to the measured product [21]. However, in practice it appears that measurement system variability can result from five categories such as standard, workplace, instrument, operator and environment, and their potential causes and subcauses (Table 1).

4 Reduction of Variations

4.1 Lean Thinking

In current manufacturing strategies, lean concepts gained prominence. This term, was coined by IMVP researcher John Krafcik as lean thinking, was meant to reflect: "less of everything" compared with mass production—half the human effort in the factory, half the manufacturing space, half the investment in tools, half the engineering hours to develop a new product in half the time. Also, it requires keeping far less than half the needed inventory on site, results in many fewer defects, and produces a greater and ever growing variety of products [22]. It is the main source of improvement of operations and thereby it influences on quality, increases productivity, reduces lead time to customers and costs [23–25] (see Fig. 3).

In lean manufacturing systems, the process control focuses on one-piece-flow. Therefore, the part can be inspected at time (i.e. by mistake proofing, visual controls or check sheets) not by random inspection or statistical quality control methods of lot samples. In a case of a defect the production line is stopped due to the application of Autonomation/Jidoka (automation with human touch) until the cause is eliminated [27, 28]. In order to prevent/detect the error occurrence false-proofing/ Poka Yoke can be integrated with the production line. It allows achieving the highest levels of quality by elimination/reduction of human errors resulting from the setup, loading, and unloading [29, 30]. Furthermore, the tools, which are implemented in lean manufacturing [31], enable to work through and eliminate overall variation in the process resulting from human activities. In order to achieve it the attention should be directly paid to the matters affecting the workers in the process where the reduction of variation is supposed to be performed, and purposely design in the actions required to achieve and sustain it. It is very crucial to underline the significant of the culture of the company and establish partnerships where particular teams doing the operations trust each other. Furthermore, the independence should be assured in finding new solutions how to achieve the results quicker, better and

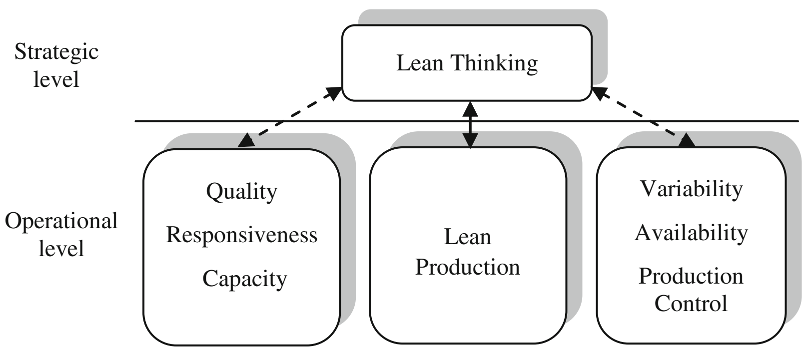


Fig. 3 Framework of lean (adapted from [26])

less expensive, and then a training, where all employees will be invited to participate, should be organized. It is known that focusing on emergencies does not allow fully committed and competent employees perform at highest performance, and thus, affecting the planned activities necessary to achieve value added. In order to solve the potential of variations, the system of Profound Knowledge can be applied. It consists of four areas:

- appreciation of a system: understanding the overall processes,
- knowledge of variation: range and causes of variation in quality, statistics in measurements,
- theory of knowledge: the concepts explaining knowledge and their limits,
- knowledge of psychology: human nature.

None of these components cannot be separated and must be managed with a delicate balance as they make up the whole system [32].

4.2 Statistical Process Control

Controlling the process variations on a component is a huge challenge as several factors can affect its functionality. In order to achieve better process control researchers apply statistical process control (SPC). This methodology aims at improving process stability and capability through reducing variability [33]. Its vital part concerns the measurement phase as it provides data indicating variation in the process. When a process is changed a signal should be generated to demonstrate it. The most common statistical process control (SPC) tools employed for monitoring process changes are control charts. However, their practical implications require certain knowledge, and understanding at all steps of SPC implementation, and a human factor is a key element (see Table 2).

4.3 Measurements and System Analysis

In order to identify components of variations researchers apply the systematic procedure of Measurement System Analysis (MSA). It is an experimental and statistical method which allows recognizing the differences in the data which result from the actual part measurements and do not refer to variation in measurement methods [33, 34]. Its purpose is to:

- Define the degree of the observed variability resulting from a measurement instrument,
- Identify the sources of variability of the measurement system,
- Evaluate the capability of a measurement instrument.

Table 2 Human factor in SPC

Step	Human factor
Preparation	Understanding statistical principles Understanding of SPC principles and goals Selection of the process, process parameters and quality characteristics Selection of measurement method Verification and ensuring measurement system capability Selection and design of control chart Selection of collection and recording data
Data collection	Accuracy of record of statistics into control chart
Control chart interpretation	Knowledge of the process variability and its causes Identification speed of the process and its variability Ability to interpret correctly control charts
Causes identification	Ability to assign correct cause to signal in control chart
Selection of action for improvement	Knowledge of the process Ability to assign adequate actions to causes
Realization of action for improvement	Speed and accuracy of realization of selected actions

MSA enables the evaluation of reliability of important input and major output data in the manufacturing process, comprehend the variations due to people, machines, materials, methods, or environment. If measurement system variation is large in comparison to part-to-part variation, such measurements may not provide useful information which can be used as a reference point for improvements [21]. According to the MSA Reference Manual, MSA defines measurement error components into two groups [19]:

- Accuracy (calibration/bias, linearity, stability),
- Precision (repeatability, reproducibility).

Further, it provides procedures on how to measure each term, however, it should be emphasized that the Gauge Repeatability and Reproducibility Studies (Gage R&R) were introduced to incorporate the procedures recommended for measurement of precision but they do not ensure accuracy related aspects [35]. The most common methods used for Gage R&R Studies are the ANOVA method and the Average and Range method. The ANOVA method is useful to determine the reproducibility variation due to its operator, operator-by-part and components, whereas the Average and Range method allows distinguishing such categories as part-to-part, repeatability, and reproducibility in the overall variation [36]. The fundamentals of MSA implementation are:

- defined number of operators, parts and repetitions that are subject of the analysis,
- operators who know the measuring instrument and procedures, and normally perform the measurement,

- a set, documented measurement procedure used by all operators,
- the values of the items selected for testing should represent the entire tolerance range,
- if possible, all the parts should be marked to avoid the impact of within-part variation,
- the resolution/discrimination of the measurement device must be small relative to the smaller of either the specification tolerance or the process variation (at least 1/10th, if this requirement is not fulfilled, process variability will not be recognized by the measurement system—its effectiveness will be blunt),
- the order of the measurement of the parts need to be randomized to avoid memorizing the values, the third party should note down the measurements, the appraiser, the trial number, and the number for each part on a table [37].

MSA is an essential first step before collecting data from the process to analyze process control or capability, to confirm that the measurement system proceeds consistently, accurately, and adequately to discriminate between parts. It should precede any data-based decision making, including Statistical Process Control, Correlation and Regression Analysis and Design of Experiments [38].

5 Conclusions

Understanding variation is a crucial aspect of managing and improving any manufacturing or product development process. In particular, it is critical to acknowledge that two types of process variation can be distinguished as actual process variation and measurement variation, both can be contained and measure using the appropriate methods. Their effective application is affected by many technical, methodical, social, environmental and economic factors. Nevertheless, one of the key elements is a human factor contribution to process variability. It is particularly visible in reference to human performance and the application of lean thinking, statistical process control and measurement system analysis.

References

1. Dubrovski, D.: The role of customer satisfaction in achieving business excellence. Total Qual. Manag. **12**(7–8), 920–925 (2001)
2. Mazur, A.: Model of OHS management systems in an excellent company. In: Antona, M., Stephanidis, C. (eds.) Universal Access in Human-Computer Interaction. Access to the Human Environment and Culture, LNCS, vol. 9178, pp. 456–467. Springer, Heidelberg (2015)
3. Jasiulewicz-Kaczmarek, M., Drożyner, P.: Maintenance management initiatives towards achieving sustainable development. In: Golinska, P., et al. (eds.) Information Technologies in Environmental Engineering Environmental Science and Engineering, pp. 707–721. Springer, Berlin (2011)

4. Miller, I., Miller, M.: Statistical Methods for Quality with Applications to Engineering and Management. Prentice Hall, Englewood Cliffs, NJ (1995)
5. Evans, J.R., Lindsay, W.M.: The Management and Control of Quality. Cengage Learning, South-Western, Andover (2011)
6. Oakland, J.S.: Statistical Process Control. Butterworth Heinemann, Oxford (2007)
7. Grzybowska, K., Gajdzik, B.: Optimisation of equipment setup processes in enterprises. J. Metalurgija. **51**(4), 563–566 (2012)
8. Kujawińska A., Rogalewicz A., Diering M., Piłacińska M., Hamrol A., Kochański A.: Assessment of ductile iron casting process with the use of the DRSA method. J. Min. Metall. Sect. B **52**(1), 17–24 (2016)
9. Bequette, B.W.: Process Control: Modeling, Design and Simulation. Prentice Hall, Upper Saddle River, NJ (2003)
10. Mrugalska, B., Akielaszek-Witczak, A., Aubrun, C.: Towards product robust quality control with sequential D-optimum inputs design. Chem. Eng. Trans. **43**, 2137–2142 (2015). doi:10.3303/CET1543357
11. Kujawińska, A., Vogt, K.: Human factors in visual quality control. Manage. Prod. Eng. Rev. **6**(2), 25–31 (2015)
12. Fontaine, C.W: Organizational Psychology Essays: Guides for a Human Capital Approach to Driving Performance. LuLu.com, Raleigh (2009)
13. Barrentine, L.B.: Concepts for R&R Studies. ASQC Quality Press, Milwaukee, WI (1991)
14. Ehrlich, B.H.: Transactional Six Sigma and Lean Servicing: Leveraging Manufacturing Concepts to Achieve World-Class Service. CRC Press LLC, Boca Raton (2002)
15. Stamatis, D.H.: Six Sigma and Beyond: Statistical Process Control, Tom 4. CRC Press LLC, Boca Raton (2003)
16. Andell, J.L.: Benefiting from Six Sigma Quality. In: ReVelle, J.B. (ed.) Manufacturing Handbook of Best Practices: An Innovation, Productivity and Quality Focus, pp. 29–48. CRC Press, Boca Raton (2001)
17. What are the sources of process variation? http://support.minitab.com/en-us/minitab/17/topic-library/quality-tools/measurement-system-analysis/basics/sources-of-process-variation/
18. Healy, S., Wallace, M.: Gage repeatability and reproducibility methodologies suitable for complex test systems in semi-conductor manufacturing, six sigma projects and personal experiences. http://www.intechopen.com/books/six-sigma-projects-and-personal-experiences/gage-repeatability-andreproducibility-methodologies-suitable-for-complex-test-systems-in-semi-condu (2011)
19. Measurement systems analysis. Reference manual, 4th ed., Chrysler Group LLC, Ford Motor Company, General Motors Corporation (2010)
20. Morris, A.S: Measurement and Instrumentation Principles. Butterworth-Heinemann, Oxford (2001)
21. Al-Refaie, A., Bata, N.: Evaluating measurement and process capabilities by GR&R with four quality measures. Measurement **43**(6), 842–851 (2010)
22. Womack, J.P., Jones. D.T., Roos, D.: The Machine that Changed the World: The Story of Lean Production. Toyota's Secret Weapon in the Global Car. Wars that is Revolutionizing World Industry. Free Press, New York (2007)
23. Keyes J.: The need for lean training. J. Manage. Policy Pract. **14**(3) (2013)
24. Sanchez, A.M., Perez, M.P.: Lean indicators and manufacturing strategies. Int. J. Oper. Prod. Manage. **21**(11), 1433–1452 (2001)
25. Wyrwicka, M.K., Mrugalska, B.: Barriers to eliminating waste in production system. In: Conference Proceedings of the 6th International Conference on Engineering, Project, and Production Management (EPPM2015), pp. 354–363, 2–4 September 2015, Gold Coast, Australia. http://www.ppml.url.tw/EPPM/conferences/2015/download/Barriers%20to%20Eliminating%20Waste%20in%20Production%20System.pdf
26. Hines, P., Holweg, M., Rich, N.: Learning to evolve: a review of contemporary lean thinking. Int. J. Oper. Prod. Manage. **24**(10), 994–1011 (2004)

27. Pettersen, J.: Defining lean production: some conceptual and practical issues. TQM J **21**(2), 127–142 (2009)
28. Sundar, R., Balaji, A.N., Satheesh Kumar, R.M.: A review on lean manufacturing implementation techniques. Procedia Eng. **97**, 1875–1885 (2014)
29. Becker, C., Scholl, A.: A Survey on Problems and Methods in Generalized Assembly Line Balancing. Eur. J. Oper. Res. **168**, 694–715 (2006)
30. Hinckley, C.M.: Combining mistake-proofing and Jidoka to achieve world class quality in clinical chemistry. Accred. Qual. Assur. **12**, 223–230 (2007)
31. Charron, R., Harrington, H.J., Voehl, F., Wiggin, H.: The Lean Management Systems: Handbook. Taylor & Francis Group, CRC Press, Boca Raton (2015)
32. Delavigne, K.T.: Deming's Profound Changes. When Will the Sleeping Giant Awaken? PTR Prentice Hall, Englewood Cliffs, NJ (1994)
33. Montgomery, D.C.: Introduction to statistical quality control, 6th edn. Wiley, New York (2009)
34. Burdick, R.K., Borror, C.M., Montgomery, D.C.: A review of methods for measurement systems capability analysis. J Qual. Technol. **35**(4), 342–354 (2003)
35. Foster, S.T.: Managing Quality: An Integrated Approach, 3rd edn. Prentice-Hall, Upper Saddle River, NJ (2006)
36. Campbell, J.: Gauge repeatability and reproducibility. Viewpoint News. http://www.viewpointusa.com/newsletter/2010_Oct/mainarticle_2010_Oct.php, October (2010)
37. Pop, L.D., Elod, N.: Improving a measuring system according to ISO/ TS 169498th International Conference Interdisciplinarity in Engineering, vol. 19, pp. 1023–1030. INTER-ENG 2014, 9–10 October 2014, Tirgu-Mures, Romania, Procedia Technology (2015)
38. Mrugalska, B., Akielaszek-Witczak, A., Stetter, R.: Robust quality control of products with experimental design. In: Popescu, D. (ed.) International Conference on Production Research—Regional Conference Africa, Europe and the Middle East and 3rd International Conference on Quality and Innovation in Engineering and Management, pp. 343–348, Cluj-Napoca, Romania, July 1–5 2014; Technical University of Cluj-Napoca; Cluj-Napoca, Romania

Part IV
Ergonomics and Environmental Design

Experimental Study on Thermal Comfort of Indoor Environment

Huimin Hu, Rui Wang, Chaoyi Zhao, Hong Luo, Li Ding and Yifen Qiu

Abstract In order to study the range of comfort environment parameters, subjective assessment and objective assessment are used in this research. The main purpose of this study is to determine the temperature and humidity range, acceptable temperature fluctuation, acceptable air flow rate and acceptable vertical air temperature difference under the thermal comfort environment in summer and winter. The thermal comfort environment should make the PMV between −0.5 and +0.5 which is recommended by international standard ISO7730. Following this principle, the comfort temperature ranges in summer and winter are determined respectively, comfort temperature range is 25–28 °C in summer and 22–25 °C in winter. Under the thermal comfort environment condition, the biggest acceptable temperature fluctuation is obtained and is 0.6 °C and the biggest acceptable air flow

H. Hu (✉) · C. Zhao · H. Luo
Ergonomics Laboratory, China National Institute of Standardization,
Beijing, China
e-mail: huhm@cnis.gov.cn

C. Zhao
e-mail: zhaochy@cnis.gov.cn

H. Luo
e-mail: luohong@cnis.gov.cn

R. Wang
Department of Building Science, School of Architecture, Tsinghua University,
Beijing, China
e-mail: 13241135966@163.com

L. Ding
Key Laboratory for Biomechanics and Mechanobiology of Ministry of Education,
School of Biological Science and Medical Engineering, Beihang University,
Beijing, China
e-mail: ding1971316@buaa.edu.cn

Y. Qiu
Laboratory for Man-Machine-Environment Engineering, School of Aeronautic
Science and Engineering, Beihang University, Beijing, China
e-mail: qiuyifen@buaa.edu.cn

M. Soares et al. (eds.), *Advances in Ergonomics Modeling, Usability & Special Populations*, Advances in Intelligent Systems and Computing 486,
DOI 10.1007/978-3-319-41685-4_35

rate is 0.5 m/s in summer. In winter, if the vertical air temperature difference is higher than 3.2 °C, the subjects feel comfortable.

Keywords Environment ergonomics · Thermal comfort · Subjective experience · PMV and PPD · Comfortable temperature range · Temperature fluctuation · Vertical air temperature difference

1 Introduction

According to statistics, there are more than 80 % of one's life time spent indoors, indoor environmental quality such as sound, light, thermal environment and indoor air quality have a significant impact on people's physical and psychological health, comfortable sensation and working efficiency [1]. Psychological researches show that people's thought, observation ability and operating skill are all in the best state when they are under the thermal comfort condition [2]. Assessment of the indoor thermal environment is more difficult due to the complex environmental factors. There are two kinds of methods to evaluate the thermal comfort which are subjective assessment and objective assessment [3]. The subjective assessment of thermal comfort can be obtained by subjective evaluation questionnaire. But the result is usually discrete [4]. Objective assessment is executed by experiments and the results turn out to be more stable and consistent. Objective assessment results, which are tested from different thermal environment laboratory, are comparable and reproductive [5]. So the combination of subjective evaluation and objective testing is the main method for evaluating thermal comfort.

There are many kinds of index to evaluate people's thermal comfort and thermal sensation. Bedford proposed 7-point thermal comfort scale (includes thermal sensation) in 1936 [6, 7]. In 1966, ASHRAE established 7 level evaluation index of thermal sensation [8]. Subjective evaluation method for thermal comfort is easy to apply and is necessary for human body thermal comfort research.

PMV (predicted mean vote)—PPD (predicted percent dissatisfied) is a widely used method for objective evaluation of thermal comfort. According to the ISO 7730, PPD values of thermal comfort environment should be less than 10 %, which means that comfortable thermal environment should make more than 90 % of the people feel satisfied. And the PMV value should be between 0.5 and +0.5 accordingly [9, 10].

In order to study the range of comfortable environment parameters, subjective assessment and objective assessment are used in this article. The main purpose of this study is to determine the comfortable temperature and humidity range, acceptable temperature fluctuation, acceptable air flow rate and acceptable vertical air temperature difference under the thermal comfortable environment in summer and winter. This research can provide foundation for thermal comfort evaluation of typical residential air conditioning room and also can guide the design of air condition system.

2 Thermal Comfort Evaluation Index—PMV and PPD

PMV (predicted mean vote)—PPD (predicted percent dissatisfied) is a widely used method for the objective evaluation of thermal comfort. The PMV model is proposed by professor P.O. Fanger and it is an index that predicts the mean value of the votes of a large group of persons on the 7-point thermal sensation scale, based on the heat balance of the human body. PMV may be calculated for different combinations of metabolic rate, clothing insulation, air temperature, mean radiant temperature, air velocity and air humidity. The PPD is an index that establishes a quantitative prediction of the percentage of thermally dissatisfied people who feel too cool or too warm. PPD can be calculated by PMV value.

Calculate the PMV using Eqs. (1)–(4):

$$PMV = \left(0.303e^{-0.036M} + 0.028\right)\left\{\begin{array}{l}(M-W) - 3.05\times10^{-3}\times[5733 - 6.99(M-W) - p_a]\\ -0.42\times[(M-W) - 58.15] - 1.7\times10^{-5}M(5867 - P_a)\\ -0.0014M(34 - t_a) - 3.96\times10^{-8}f_{cl}\\ \times\left[(t_{cl}+273)^4 - (\bar{t}_r+273)^4\right] - f_{cl}h_c(t_{cl} - t_a)\end{array}\right\} \quad (1)$$

$$\begin{aligned}t_{cl} &= 35.7 - 0.028(m-w)\\ &\quad - I_{cl}\left\{3.96\times10^{-9}f_{cl}\times\left[(t_{cl}+273)^4 - (\bar{t}_r+273)^4\right] + f_{cl}h_c(t_{cl} - t_a)\right\}\end{aligned} \quad (2)$$

$$h_c = \begin{cases}2.38\left(t_{cl} - t_a\right)^{0.25} & 当\ 2.38\left(t_{cl} - t_a\right)^{0.25} > 12.1\sqrt{v_{ar}}\\ 12.1\sqrt{v_{ar}} & 当\ 2.38\left(t_{cl} - t_a\right)^{0.25} < 12.1\sqrt{v_{ar}}\end{cases} \quad (3)$$

$$f_{cl} = \begin{cases}1.00 + 1.290I_{cl} & 当\ I_{cl} \le 0.078\ m^2\cdot ℃/W\\ 1.05 + 0.645I_{cl} & 当\ I_{cl} > 0.078\ m^2\cdot ℃/W\end{cases} \quad (4)$$

where

- M is the metabolic rate, in watts per square metre (W/m^2);
- W is the effective mechanical power, in watts per square metre (W/m^2);
- I_{cl} is the clothing insulation, in square metres kelvin per watt (m^2 K/W);
- f_{cl} is the clothing surface area factor;
- t_a is the air temperature, in degrees Celsius (°C);
- t_r is the mean radiant temperature, in degrees Celsius (°C);
- v_{ar} is the relative air velocity, in metres per second (m/s);
- p_a is the water vapour partial pressure, in pascals (Pa);
- h_c is the convective heat transfer coefficient, in watts per square metre kelvin [W/(m^2 K)];
- t_{cl} is the clothing surface temperature, in degrees Celsius (°C)

Note: 1 metabolic unit = 1 met = 58.2 W/m^2; 1 clothing unit = 1 clo = 0.155 m^2°C/W.

The PMV predicts the mean value of the thermal votes of a large group of people exposed to the same environment. But individual votes are scattered around this mean value and they are useful to be able to predict the number of people likely to feel uncomfortably warm or cool.

The PPD is an index that establishes a quantitative prediction of the percentage of thermally dissatisfied people who feel too cool or too warm.

With the PMV value determined, calculate the PPD using Eq. (5),

$$PPD = 100 - 95 \cdot \exp\left(-0.03353 \cdot PMV^4 - 0.2179 \cdot PMV^2\right) \tag{5}$$

3 Test Equipment and Method

Artificial environment laboratory
Experiments have been conducted in the artificial environment laboratory which is 4.20 m long, 3.8 m wide and 2.5 m high. There are 125 platinum resistance thermometers which are arranged as 5 × 5 × 5 to test the temperatures of the room. Black-bulb thermometer is used to test the radiation temperature; hygrometer and anemometer are also used in the experiment. Air conditioning installation height is 2.2 m. The outdoor environment parameters are controlled by climatic chamber. Artificial environment laboratory and test points are shown in Fig. 1a. Based on the main posture of human in daily life, the position of temperature test point in vertical direction is determined and shown in Fig. 1b.

Subjects selection and subjective test
The region, age, gender and BMI (Body Mass Index) are considered in subject selection. Positive mental attitude, basic knowledge about thermal comfort, healthy body and serious attitude are also very important for subject. The details about subjects are shown in Table 1.

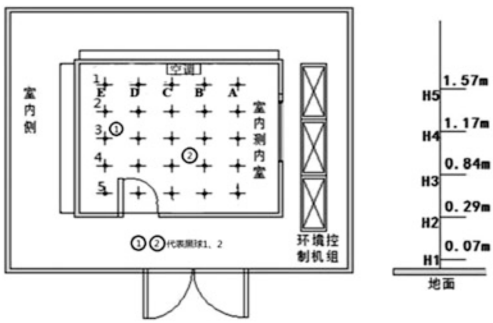


Fig. 1 Schematic diagram of thermal comfort test room

Table 1 The details about subjects

Subjects groups		Number
Old aged group (55–70 years old)	Male	3
	Female	3
Middle aged group (35–55 years old)	Male	3
	Female	3
Young group (16–35 years old)	Male	3
	Female	3
Children group (7–15 years old)	Male	3
	Female	3

Experimental procedures are as follows:

1. Adjust the indoor temperature and humidity to the target and keep them stable. The target temperature fluctuation range should be less than ±0.2 °C, the difference between two black-bulb thermometer should be less than 0.2 °C, and the humidity fluctuation range should be less than 3 %.
2. Subjects wear test clothes for summer and winter condition. The summer test clothes include underpants, short sleeve, shorts and shoes, and the total thermal insulation is 0.26 clo. The winter clothes include underpants, cotton pajamas, socks and shoes, and the total thermal insulation is 0.9 clo.
3. Subjects enter into test room and experience the thermal environment. Subjects can move or stand anywhere in the room, then feel the temperature, humidity and draught. After 10 min, the subjects should finish the questionnaire.
4. Collect questionnaire and then subjects have a rest in waiting room. When the room was set as another condition and keeps stable (about 40 min), subjects enter into the test room and conduct another experiment.

4 Experiment Results in Summer

Comfortable temperature range
A total of seven temperatures including 24, 25, 26, 27, 28, 29, 30 °C were tested. The relative humidity was kept in 50 ± 5 %. 7-point thermal sensation scale was used in subjective test and evaluation criteria. The comfortable temperature range are established according to the result of subjective evaluation. If the test result is between −1 and +1, we believe that this test temperature is comfortable. The test results are shown in Table 2.

From the test results about acceptable rate in different temperature shown in Table 2, it can be found that the highest acceptable rate is 78 % and corresponding test temperature is 27 °C. If the temperature is between 25 and 28 °C, the average acceptable rates are 66.5 % which is nearly 70 %. Base on the above analysis, 25–28 °C is considered as the comfortable temperature range in summer. There is

Table 2 Acceptable percentage for each test temperature in summer condition

Subjects groups	Acceptable rate in each temperature						
	30 °C	29 °C	28 °C	27 °C	26 °C	25 °C	24 °C
Children group (%)	0	80	100	86	83	43	12.5
Young group (%)	0	33	83	87.5	67	80	60
Middle aged group (%)	0	50	67	83	86	75	0
Old aged group (%)	17	33	29	50	29	25	33
Average acceptable rate (%)	4	43	65	78	65	58	25

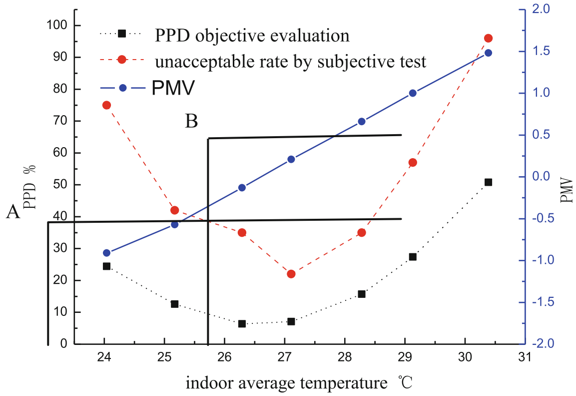


Fig. 2 PMV/PPD and subjective evaluation result in summer

another finding that the preferred comfortable temperatures for people in different ages are different.

While taking the subjective test, the objective tests were also conducted which include collecting the air temperature, humidity, radiation temperature and air flow rate. Based on these collected data the PMV and PPD are calculated.

The objective evaluation results based on the PMV-PPD and the subjective evaluation results are shown in Fig. 2.

It can be found from Fig. 2 that the minimum dissatisfied rate is 22 % and the corresponding temperature is 27 °C. The changing tendency of the dissatisfied rate from subjective evaluation and PPD from objective test are the same, but dissatisfied rate from subjective evaluation is higher than the PPD. It is because that PPD is calculated by the average parameter of test room, but the indoor environment is not uniform actually. So even if the average temperature in the test room is comfortable for people, but the temperatures are not the same in different positions, so there may be some dissatisfied positions. The thermal comfortable environment for B type condition should make the PMV between −0.5 and + 0.5 which is recommended by ISO7730. Following this principle, the comfort temperature range is determined to be 25–28 °C in summer condition.

4.1 Acceptable Temperature Fluctuation

In the natural environment, the temperature keeps unchanged in a relatively short period. In an artificial environment, air condition, heating radiator and electric fan are often used to control the environment parameters. During the running process of those equipments, the mechanical cycle (e.g. blades swing of air condition) may cause big temperature fluctuation in short time. This kind of temperature fluctuation would cause discomfort to human body.

In order to obtain the acceptable temperature fluctuation, the related experiment was conducted in the summer condition. Based on the subjective evaluation from subjects, the acceptable temperature fluctuation was determined. In this experiment, the cycle of temperature fluctuation is 7 min, which is the typical work cycle of most air conditioners. In the comfortable temperature range (25–28 °C), the acceptable temperature fluctuation is shown in Table 3.

According to the comfortable temperature range in summer condition, we can see from Table 3 that the upper limit of acceptable temperature fluctuation is independent of environment temperature. Based on the result shown in Table 3, it can be concluded that the biggest acceptable temperature fluctuation is 0.6 °C.

Acceptable air flow rate

The higher airflow rate will make the indoor temperature uniform, but it also cause strong draft sensation and make discomfort. The smaller airflow rate will lead to non-uniform temperature of indoor environment. So it is very necessary to determine the highest acceptable air flow rate through the human thermal sensation experiment.

Based on the subjective evaluation from subjects, the highest acceptable air flow rate was determined. The results are shown in Table 4. Under the comfortable temperature conditions of summer, it can be seen from Table 4 that the highest acceptable air flow rate is independent of ambient temperature, it can be considered that the highest acceptable air flow rate is 0.5 m/s.

Table 3 The acceptable temperature fluctuation in summer

Environment temperature (°C)	25	26	27	28
Acceptable temperature fluctuation (°C)	0.6	0.7	0.6	0.6

Table 4 The t acceptable air flow rate in summer

Environment temperature (°C)	25	26	27	28
Highest acceptable air flow rate (m/s)	0.52	0.45	0.47	0.53

5 Experiment Results in Winter

Comfortable temperature range

The rule of determining the comfort temperature range in winter is the same to summer. Seven temperatures such as 24, 25, 26, 27, 28, 29, 30 °C are tested in winter. The relative humidity of the test environment is 50 ± 5 %. The test results are shown in Table 5.

From Table 5 it can be seen that the highest acceptable rate is 87.5 % and the corresponding temperature is 23 °C. When the temperature is between 22 and 25 °C, the average acceptable rates of all test groups is higher than 63 %, so the temperature range (22–25 °C) is considered to be the comfortable temperature scope in winter. At the same time we find that the preferred temperatures are different for different aged groups.

Figure 3 gives both the objective evaluation result (PMV and PPD) and the subjective evaluation result.

It can be known from Fig. 3 that the lowest dissatisfied rate is 13 % and the corresponding temperature is 23 °C. The thermal comfort environment should make the PMV between −0.5 and +0.5 which is recommended by B type condition

Table 5 Acceptable percentage for each test temperature in winter condition

Subjects groups	Acceptable rate in each temperature						
	26 °C	25 °C	24 °C	23 °C	22 °C	21 °C	20 °C
Children group (%)	33	50	67	100	67	50	67
Young group (%)	17	67	100	100	67	67	60
Middle aged group (%)	67	100	83	80	67	67	33
Old aged group (%)	33	83	83	83	100	17	33
Average acceptable rate (%)	37.5	79.2	81.8	87.5	63.6	50.0	47.8

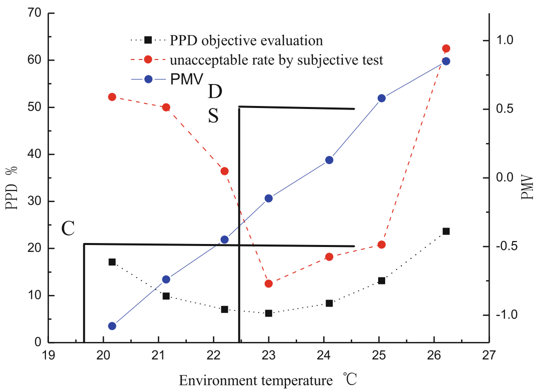


Fig. 3 PMV/PPD and subjective evaluation results in winter

Table 6 Acceptable temperature fluctuation in winter

Environment temperature (°C)	22	23	24	25
Acceptable temperature fluctuation (°C)	0.68	0.82	1.42	1.3

of international standard ISO7730. Following this principle, the comfortable temperature scope is determined to be 22–25 °C in winter condition.

Acceptable temperature fluctuation

The determined criterion about the biggest acceptable temperature fluctuation in winter is the same as the way in summer condition. In the comfortable temperature scope (25–28 °C), the biggest acceptable temperature fluctuation is shown in Table 6.

We can see from Table 6 that the biggest acceptable temperature fluctuation increases with the increase of environment temperature. Compared with the summer test result about acceptable temperature fluctuation, it can be found that the acceptable temperature fluctuation in winter is higher. It is because when people wear thicker clothes in winter their sensitivity to temperature fluctuations becomes lower.

Acceptable vertical air temperature difference

In winter, low temperature will make blood vessels shrink and slow the metabolism of blood. The flow rate of blood will become slower in winter and make hands and feet feel cold. Especially, fingers and toes will feel cold for a long time and make human body feel very discomfort. So, vertical air temperature difference is an important parameter for evaluating the environment thermal comfort in winter. In order to build a comfortable environment in winter, the temperature around feet should be increased. The test process of acceptable vertical air temperature difference is as follow: firstly, adjust the environment temperature around the head to the comfort temperature (23 °C), then increase environment temperature around the feet from 23 to 30 °C (vertical air temperature difference increase from 0 to 7 °C), at last record the subjective thermal sensation results in each test condition. The results are shown in Fig. 4.

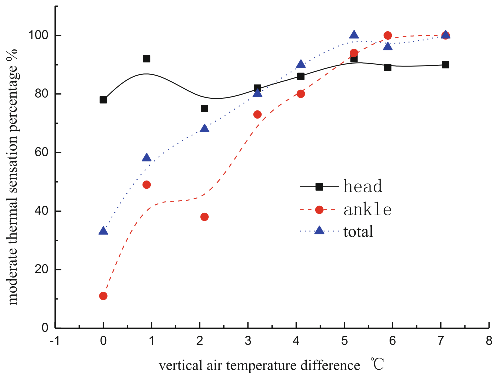


Fig. 4 Thermal sensation and vertical air temperature difference

It can be known from Fig. 4 that the moderate thermal sensation percentage increases with the temperature's increase around feet. The higher temperature around feet is, the more satisfied human body feel. When the temperature around feet is higher than around head, it will increase the thermal comfortable sensation of human body. The experimental results shows temperature around feet is 3.2 °C, which is higher than that of around head, it can make more than 75 % of people feel satisfied. So it can be believed that when the vertical air temperature difference (the temperature around head is higher than that of around the feet) is higher than 3.2 °C, the subjects will feel comfortable.

6 Conclusions

In order to study the comfort range of environment parameters, subjective assessment and objective assessment are all used in this research. The main purpose of this study is to determine the temperature and humidity range, acceptable temperature fluctuation, acceptable air flow rate and acceptable vertical air temperature difference under the different thermal comfortable environment both in summer and winter. Research results showed that:

1. It has the same tendency for the dissatisfied rate from subjective evaluation and PPD from objective test, but dissatisfied rate from subjective evaluation is higher than that of PPD. It is because that the PPD is calculated by the average parameter of test room, but the indoor environment is not uniform actually, so if the average temperature is comfortable to people but the temperatures are not the same in different point, it may also cause dissatisfaction even in some position.
2. The thermal comfortable environment should make the PMV between −0.5 and +0.5 which is recommended by international standard ISO7730. Following this principle, the comfortable temperature ranges in summer and winter are determined respectively. The comfort temperature range is 25–28 °C in summer and 22–25 °C in winter.
3. Under the thermal comfortable environment condition, the biggest acceptable temperature fluctuation is 0.6 °C while the biggest acceptable air flow rate is 0.5 m/s in summer.
4. In winter, vertical air temperature difference between head and feet is an important parameter to influence the thermal comfort of people. The result of the research is that if the vertical air temperature difference (the temperature around head is higher than that of foot) is larger than 3.2 °C, the subjects will feel comfortable.

References

1. Xu, X., Li, B.: Influence of indoor thermal environment on thermal comfort of human body. J. Chongqing Univ. **4**(28), 102–105 (2005)
2. Li, S., Lian, Z.: Discussions on the application of Fanger's thermal comfortable theory. In: Shanghai Refrigeration Institute Academic Annual Conference (2007)
3. Holmér, I., Nilsson, H., Bohm, M., et al.: Thermal aspects of vehicle comfort. Appl. Hum. Sci. J. Physiol. Anthropol. **14**(4), 159–165 (1995)
4. Ye, H., Wei, R.: Evaluation indices of thermal environment based on thermal manikin. Chin. J. Ergonomics **11**(2), 26–28 (2005)
5. Tanabe, S., Zhang, H., Arens, E.A., et al.: Evaluating thermal environments by using a thermal manikin with controlled skin surface temperature. Ashrae Trans. **100**, 39–48 (1994)
6. Zhu, Y.: Building Environment. China Building Industry Press, Beijing (2010)
7. Bedford, T.: The warmth factor in comfort at work. Rep. Industr. Health Res. **76**(5), 45–60 (1936)
8. ASHRAE. ANSI/ASHRAE Standard 55-1992, Thermal Environmental Conditions for Human Occupancy. Atlanta, GA (1992)
9. Nilsson, H.O., Holmér, I.: Comfort climate evaluation with thermal manikin methods and computer simulation models. Indoor Air **13**(1), 28–37 (2003)
10. Liu, W., Lian, Z., Liu, Y.: Heart rate variability at different thermal comfort levels. Eur. J. Appl. Physiol. **103**(3), 361–366 (2008)

Ergonomic Assessment of Environmental Conditions in Public Elementary School Classrooms in Quezon City, Philippines

Cyndi Marie De Guzman, Alessandra Fajardo, Francis Miguel Hubag and Benette Custodio

Abstract Majority of the conducted studies about public elementary classrooms in the Philippines focuses on anthropometrics but research about the physical environmental factors that affect learning is lacking. With this, an ergonomic assessment of four public elementary schools in Quezon City, Philippines was conducted to determine if the facilities are able to meet the recommended thermal, acoustical, and lighting ergonomic standards for classrooms and assess if the facilities are conducive environments for learning. Acoustic, thermal, and lighting measurements were collected from four different locations inside each classroom. Simultaneously, a survey of students was conducted to determine their perception of the conditions of their classroom in terms of thermal, visual and acoustical comfort. The results were compared to the general ergonomic standards for classrooms and showed that the environmental conditions of the public elementary school classrooms considered are not conducive for learning based on the thermal, acoustical, and lighting standards.

Keywords Ergonomics · Ergonomic assessment · Public elementary classrooms · Temperature Illuminance · Sound

1 Introduction

With the growing population in the Philippines, the need for educational facilities has also increased. Due to the country's limited resources, many public school classrooms are becoming overcrowded and are accommodating more students than their recommended capacities. In the urban areas, where congestion problems are common, larger class sizes and student to teacher ratios are prevalent. Some schools have resorted to conducting multiple shifts of classes in order to accommodate the

C.M. De Guzman (✉) · A. Fajardo · F.M. Hubag · B. Custodio
Department of Industrial Engineering and Operations Research,
University of the Philippines, Diliman, 1101 Quezon City, Philippines
e-mail: cyndideguzman@gmail.com

M. Soares et al. (eds.), *Advances in Ergonomics Modeling, Usability & Special Populations*, Advances in Intelligent Systems and Computing 486,
DOI 10.1007/978-3-319-41685-4_36

demand of students. Because of the congestion of students and other factors such as the building structures and locations, the physical environment of the classrooms may be compromised and this can influence the students' learning.

News articles about the current state of public school educational facilities in the Philippines usually describe them as an environment not conducive for learning, but there is a lack of quantitative data to back up these claims. Most studies regarding the classrooms in the country revolve around anthropometrics and take into account the analysis of the furniture used by the students. Research regarding the other environmental factors that contribute to the students' comfort is lacking.

As of 2010, the Department of Education (DepEd) has developed an educational facilities manual for public schools that contains their standards for classrooms in terms of ergonomic factors such as anthropometry, visual comfort, thermal comfort, acoustic comfort and color, most of which have yet to be quantified. Maintaining the recommended levels of these factors is very important to provide a comfortable learning environment for the students especially since they spend most of their time in these classrooms ranging from 6 to 8 h a day.

From this, public elementary schools in the Philippines are claimed to be not conducive to learning, but the only consideration made is due to class size. This resulted from the lack of quantitative environmental ergonomic standards in analyzing the conduciveness of Public Elementary School classrooms in the country.

1.1 Objectives of the Study

The study aims to assess the environmental conditions of public elementary school classrooms in Quezon City in terms of thermal, acoustical, and lighting factors, determine the compliance of the public elementary school classrooms in Quezon City in accordance to the general ergonomic standards on learning environments, and assess whether or not the Philippine government standards set by the Department of Education are ergonomically acceptable.

1.2 Scope and Limitation

This study focused on the physical environmental factors which greatly affect classroom learning that can be measured quantitatively specifically thermal, acoustical, and lighting standards.

In performing the study, a sample was considered from all the public elementary schools in Quezon City. Public schools were considered since these are the schools who are directly managed by the Department of Education. Moreover, Quezon City was considered as the focus of the study since it has the highest population in the National Capital Region (NCR), having a population of 2,761,720. Lastly, only the assessment of environmental conditions of elementary school classrooms of Grades 4–6 were considered in the study since developmental learning of human is crucial during these ages.

2 Methodology

In order to represent an unbiased sample of the public elementary schools in Quezon City, Philippines, the number of samples was determined and 4 schools that represent the extremes of every factor considered were chosen.

Acoustic, thermal, and lighting measurements were gathered. Four points were determined per school facility. As shown in Fig. 1, the four points are named as Point 1 for the part of the classroom at the center and near front, Point 2, for the side of the classroom near the hallway, Point 3 for the back of the classroom, and Point 4 for the side of the classroom near the road or outside of the school. These were considered as sample measurements per classroom. With this, the sample mean measurement per environmental factor was compared to the standard measurements. This assessment determined the compliance of the public elementary school classrooms to the set standard ergonomic measurements on learning environments.

Simultaneously, students were asked to answer a survey (see Appendix) which uses a Likert scale in order to determine students' relative assessment on the conditions of their learning environment in terms of thermal, visual and acoustical comfort. The survey also aims to determine the percentage of the population that is affected by the extreme factors. The population that will be studied will be the students that are exposed to the extreme factors. All data gathered were analyzed using descriptive statistics.

The selected schools were determined based on the extremes of every factor, as stated. For illuminance, no specific pair of schools was chosen since the amount of

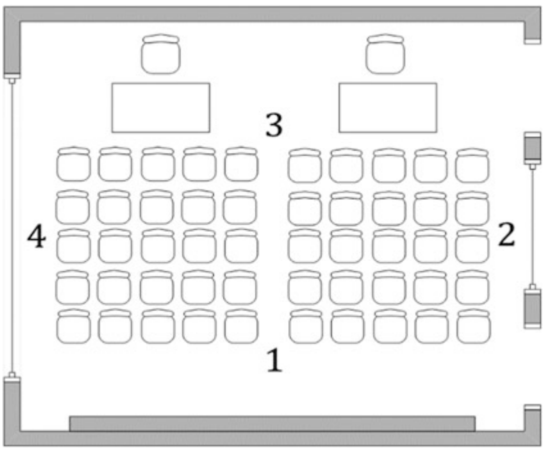


Fig. 1 Locations of data points per classroom

natural illumination was based from the structure of the buildings, if they permit natural sunlight to enter the classrooms. With this, the group measured the illuminance of the schools chosen for the other two factors. Meanwhile, the noise factor was based from the location of the school, if it is located near a highway or railroad, or far away from the said causes of noise pollution. Sauyo Elementary School is at least 1.29 km away from a secondary road while Commonwealth Elementary School is directly along a secondary road in Quezon City. Lastly, temperature was based from the enrolment population of the students since the main factor affecting air ventilation of classrooms is the carbon dioxide emitted by students inside the classrooms. San Jose Elementary School has recorded enrollees of 251 for the year 2011–2012 while Rosa L. Susano—Novaliches Elementary School has a recorded enrollees of 8518 for the year 2011–2012, and still the highest last 2014–2015.

3 Results and Discussion

According to statistical analysis, the model assumed by the group that was used to assess the environmental conditions of public elementary schools in Quezon City, Philippines has a significance with a p-value of <0.0001 at a 95 % confidence level. It can be shown that the environmental factors (temperature, illuminance, and sound) and the location of the measurement inside the classroom (Point 1, Point 2, Point 3, and Point 4) has a significant effect to the measurements gathered by the group. Thus, the temperature level, illuminance level, and noise level are affected by the location. On the other hand, the school and the shift (i.e. AM shift, PM shift) do not have a significant effect (see Appendix).

Furthermore, using the general factorial in determining the significance of the interaction between the categorical variables (i.e. school, location, environmental factor, shift), the only significant interaction is the interaction of the location and the environmental factor with a p-value of 0.0007 at a 95 % level of significance. Looking at the mean squares as shown on the effects list (see Appendix), the highest interaction among the variables considered is the interaction between the location of the measurement and the environmental factors. This shows that there is a significance in considering the location and the environmental factor that will be measured at that location. This has led to the further assessment of the environmental conditions of the classrooms as backed up by the statistical analysis conducted.

The temperature range used as the standard temperature for the analysis of data is based on the adjusted range for tropical areas from the assessment of the ASHRAE Standard 55 criteria for thermal comfort from Alison Kwok's study. All measurements gathered as seen in Fig. 2 are beyond the thermal comfort zone based on the standard range and the mean.

Temperature measurements of San Jose Elementary School (SJES) are generally higher than that of Rosa L. Susano Elementary School (RLSES). The measurements for both schools are also high compared to the mean temperature of Metro Manila

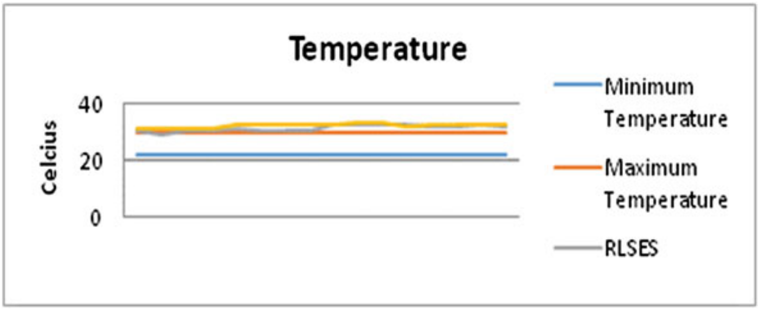


Fig. 2 Temperature

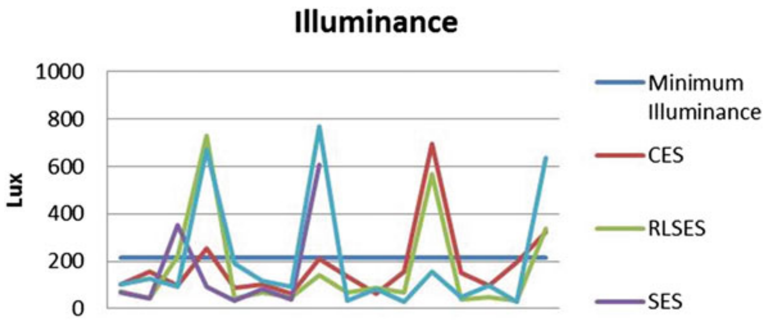


Fig. 3 Illuminance

from PAG-ASA which is 28.3 °C especially that the measurements were gathered in the latter months of the year which are supposed to be the relatively cooler months in the Philippines.

The illumination level used in the analysis is based on the standards as set by the Illuminating Engineering Society that recommended 20 foot candles or approximately 215 lx for people below 25 years old when engaged in reading and writing activities which compose majority of the activities of students in elementary schools. 12 measurements out of 56 measurements are acceptable since they exceeded the minimum recommended illuminance level, as seen in Fig. 3. Majority of these acceptable measurements are from location 4 which is closest to the window that allows natural light to pass through it. Overall, the illuminance levels of the classrooms measured are not able to meet the recommended standards. In addition, they are not able to meet the prescribed 20–40 foot candles lighting standard of the Department of Education facilities manual.

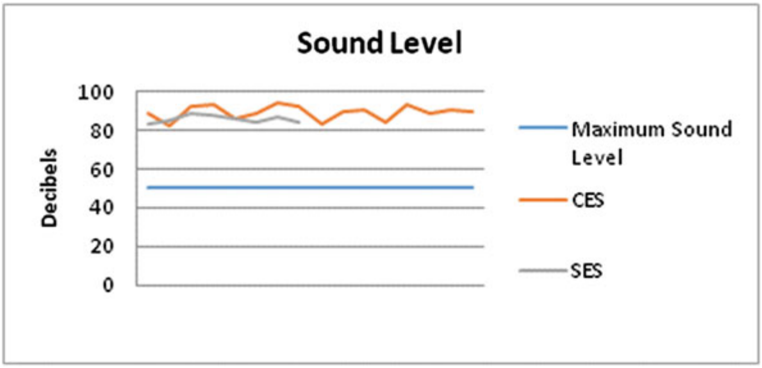


Fig. 4 Sound level

Lastly, the standard measure for maximum sound level of 50 dBA in the occupied classroom used for analysis of the data is based from a study conducted about noise levels in primary school in Hong Kong. Figure 4 shows a comparison between the temperature measurements and Commonwealth Elementary School (CES) and Sauyo Elementary School (SES). All measured values for both schools are not acceptable since they exceed the 50 dBA standard. In addition, if the measurements are compared to the recommended range of noise level of 30–80 dBA, the values are still not acceptable. The high sound levels in the classrooms of both schools are due to the noise coming from outside the classrooms (noise from road, ongoing activities in the school, noise created by other rooms) and from the noise created by the students inside the room. The sound level measurements of Sauyo Elementary School are generally lower than that of Commonwealth Elementary School with all measured values below 90 dBA as compared to 8 measurements above 90 dBA (Fig. 5).

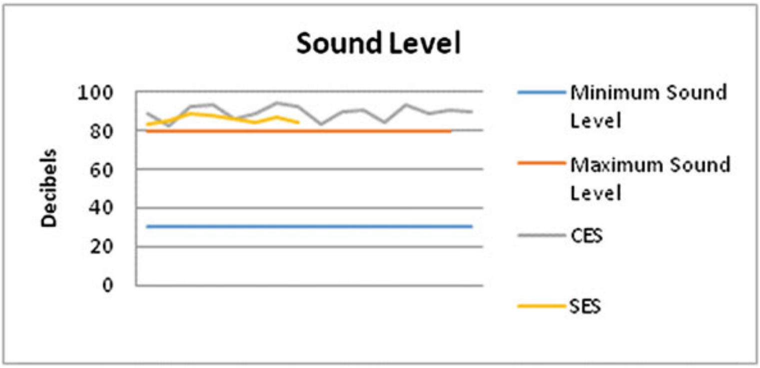


Fig. 5 Sound level

Looking at the acceptability of the students on their learning environment through the conducted survey, 52 % of the students of Rosa L. Susano Elementary School (RLSES) rated their overall comfort as Just Right while 31.33 % of the students of San Jose Elementary School (SJES) rated their overall thermal comfort to be Slightly Warm. Though SJES has smaller population than RLSES, as observed, the reason why students in SJES feel slightly warm than RLSES may be due to the conditions of the facilities of the two schools. It was observed that there are more working fans in RLSES than in SJES which may have caused a relatively cooler temperature than the latter.

However, majority of the students from both schools, at a percentage of 74 and 51 % at RLSES and SJES respectively, desire an overall cooler temperature inside their classrooms.

Meanwhile, the students of Commonwealth Elementary School (CES), Rosa L. Susano Elementary School (RLSES), Sauyo Elementary School (SES), and San Jose Elementary School (SJES) perceive that there are no problems on the overall brightness of their classrooms. Also, the illuminance level on their learning environment does not affect their reading and writing capability negatively. Majority of the students answered "Yes, bright" and "Yes, I can read and write because of the light", while almost none had a problem in terms of illuminance.

Fifty-nine percent (59 %) of the students rated the overall noise in their classrooms as neutral. At an approximate of 1.29 km away from the main road, the only noise that the school is exposed is from the noise of the nearby residences and a multi-purpose hall closely beside the school. On the other hand, a 2 % difference can be observed on the answer of the students of CES at 43 % saying neutral and 41 % saying that they can hear something from the outside of the room. Consequently, majority of the students from both schools said that the noise disturbs them.

These may cause the students to misunderstand what the teacher is saying find it difficult to read or write when the classroom is noisy. Also, the overall willingness of the students to listen to the teacher declines as they lose the will to pay attention in class when it is noisy.

4 Conclusion

It has been observed that the public elementary classrooms in Quezon City are not conducive to learning based from the quantitative measurements of the temperature level, illuminance level, and sound level in four different locations (i.e. center-front, side of the classroom near the hallway, back of the classroom, side of the classroom near the road) inside the classroom as they are not able to meet the recommended standards of visual, thermal and acoustical comfort for classrooms.

The temperature measured in the classrooms exceeds the prescribed thermally acceptable range for tropical areas. The sound level in the classrooms exceed the 50 dBA maximum recommended exposure value for occupied classrooms and may increase the risks of hearing impairment in the students and teachers that are exposed to the high sound levels for long periods of time. Although the illuminance level for certain locations proved to be acceptable, the illuminance is not even throughout the classrooms therefore are not able to provide enough light to all the students in the classroom so that they can study comfortably.

5 Recommendations

In order to deliver the most effective learning experience to the students, the administration of every school should assure that the classrooms that are built adhere to the general ergonomic standards on learning environments. With this, the learning of the students will not be compromised. Moreover, the administration of every school should assure that the facilities in every classroom will not sacrifice the thermal comfort, lighting comfort, and the acoustical comforts of the students. Since the classrooms are not conducive to the learning of the students, the school should be subjected to the recommendation of the group for reconstruction and reevaluation of the facility for further improvements in terms of ergonomic concerns.

Appendix

ANOVA for Selected Factorial Model

Questionnaire No.

Age: | **Date:**

Gender: | **Time:**

Panuto: Markahan ng ekis [X] ang kahon sa gilid ng iyong sagot sa bawat bilang. *(Put an "X" beside the box of your chosen answer for each number.)*

THERMAL COMFORT

1. **Ilarawan ang temperature sa inyong silid-aralan.** *(Please rate the overall thermal comfort in the classroom.)*

Masyadong malamig *(Cold)*	Malamig *(Cool)*	Medyo malamig *(Slightly Cool)*	Katamtaman *(Just Right)*	Medyo mainit *(Slightly Warm)*	Mainit *(Warm)*	Masyadong Mainit *(Hot)*

2. **Sana ang silid-aralin ay** *(I would want the classroom to be)*

Mas malamig *(Cooler)*	Walang pagbabago *(No Change)*	Mas mainit *(Warmer)*

VISUAL COMFORT

3. **Maliwanag ang silid-aralan.** *(The classroom is well-lit)*

Oo *(Yes)*	Neutral	Hindi *(No)*

4. **Nakakabasa at nakakapagsulat ako nang maayos dahil maliwanag sa silid-aralan.** *(I am able to read and right properly with the classroom's lighting.)*

Oo *(Yes)*	Neutral	Hindi *(No)*

ACOUSTICAL COMFORT

5. **Wala akong ingay na naririnig mula sa labas ng silid-aralan.** *(The classroom is free from noise coming from the outside of the classroom.)*

Oo *(Yes)*	Neutral	Hindi *(No)*

6. **The noise disturbs me in the classroom**

Oo *(Yes)*	Neutral	Hindi *(No)*

7. **Hindi ko nauunawaan ang sinasabi ng guro tuwing maingay sa silid-aralan.** *(I misunderstand what the teacher says when the classroom is noisy.)*

Oo *(Yes)*	Neutral	Hindi *(No)*

8. **Nahihirapan akong magbasa at magsulat tuwing maingay sa silid-aralan.** *(I find it difficult to read or write when the classroom is noisy.)*

Oo *(Yes)*	Neutral	Hindi *(No)*

9. **Nawawalan ako ng ganang making sa tinuturo ng guro sa tuwing maingay sa silid-aralan.** *(I lose the will to pay attention in class when it is noisy.)*

Oo *(Yes)*	Neutral	Hindi *(No)*

Analysis of variance table (Classical sum of squares—type II)						
Source	Sum of squares	df	Mean square	F value	*p*-value prob > F	
Model	6.249E+005	8	78,108.10	5.80	<0.0001	Significant
A-School	6187.64	2	3093.82	0.23	0.7953	
B-Location	2.599E+005	3	86,648.08	6.44	0.0007	
C-Envi factor	3.550E+005	2	1.775E +005	13.18	<0.0001	
D-Shift	3762.93	1	3762.93	0.28	0.5989	
Residual	8.481E+005	63	13,461.96			
Cor total	1.473E+006	71				

Effects List of First Replicate (R1:R1)

Term		df	Sum of squares	Mean square
Model	A-School	2	6187.64	3093.82
Model	B-Location	3	2.599E+005	86,648.08
Model	C-Envi factor	2	3.550E+005	1.775E+005
Model	D-Shift	1	3762.93	3762.93
Model	AB	6	17,489.49	2914.91
Model	AC	4	13,936.05	3484.01
Model	AD	2	27,573.08	13786.54
Model	BC	6	5.199E+005	86650.04
Model	BD	3	1174.86	391.62
Model	CD	2	7003.81	3501.90
Model	ABC	12	35269.67	2939.14
Model	ABD	6	55427.37	9237.90
Model	ACD	4	54624.29	13656.07
Model	BCD	6	2083.03	347.17
Model	ABCD	12	1.136E+005	9468.48

Practical Urban: The Urban Furniture and Its Relationship with the City

Amilton Arruda, Isabela Moroni, Pablo Bezerra, Paulo Silva and Rodrigo Balestra F. de Paiva

Abstract This article explains the concepts of city and urban practices—phenomena of urban activity—that directly influence the deployment of street furniture and, above all, the importance given to them by the population, with regard to its true functions, identity, meaning (symbology), uses and appropriations. It is vitally important for the study also understand the urban furniture relation to the design of cities, is to complement the public space, is the way interferes with the urban landscape. You have to understand how society is shown in front of herself and the world itself that surrounds it, and what are the devices that make city living when connect—through uses and customs—as this is the vital forces of individuals and community space practices created by the tactics of the inhabitants to allow its ambiance, wellness, safety and comfort, sensations often perceived by the set of elements that constitute the urban furniture of cities.

Keywords Urban practices · Urban furniture · Urban landscape

1 Introduction

The city as a backdrop of urban practices. Key issue in many disciplines, the city is always a recurring theme for scholars seeking to understand this phenomenon of human activity. The history of the city in a little account of the creation of urban space and its manifestations, its functions, transformations and complexity with which we are currently faced with various city typologies around the planet. There is no definition that applies itself to all its manifestations nor isolated description

A. Arruda · I. Moroni · P. Bezerra · P. Silva
Centro de Artes e Comunicacão, Universidade Federal de Pernambuco, Recife-PE 50670-901, Brazil

R.B.F. de Paiva (✉)
Faculdade de Artes Visuais, Universidade Federal de Goiás, Campus Samambaia, Goiânia-GO CEP 74690-900, Brazil
e-mail: rodrigobalestra@gmail.com

M. Soares et al. (eds.), *Advances in Ergonomics Modeling, Usability & Special Populations*, Advances in Intelligent Systems and Computing 486,
DOI 10.1007/978-3-319-41685-4_37

that covers all its transformations, from the embryonic social nucleus to the complex shapes of their maturity and bodily disintegration of his age. The city's origins are obscure, buried or irretrievably erased a large part of his past, and are difficult to weigh its future prospects. If we want to launch new foundations for urban life, we must understand the historical nature of the city and distinguish between their original functions, those which it emerged and those that can still be invoked. In our attempt to get a better view of its current state, we should peek over the line of the historical horizon in order to glimpse the dark traces of more ancient structures and even more primitive functions. However, not abandon this path as not to have followed in all its intricacies and setbacks, through the five thousand years of recorded history, until the emerging future. The author continues to write the city's origins to explain the transformations that the man experienced throughout history and that determined, so to speak, its model of social behavior in the cities: before the city, there was a small village, the sanctuary and the village; before the village, the camp, the hiding, the cave, the stone heap; and above all this, there was a certain predisposition to social life that man shares, of course, with several other animal species. At all levels of life, return to mobility for security or, conversely, immobility for adventure [1].

In the Park of words: "The city is more than a jumble of individual men and social conveniences, streets, buildings, electricity, tramways, telephones; It is something more than a mere constellation of institutions and administrative arrangements—courts, hospitals, schools, police and civil servants of various kinds. The city is a state of mind, a body of customs and traditions and feelings and organized attitudes inherent to these customs and transmitted by this tradition. The city is not merely a physical mechanism and an artificial construction. It is involved in vital processes of the people who compose it; It is a product of nature, and especially of human nature" [2]. With the industrial revolution and the emergence of the steam engine in the mid-eighteenth century, we began the industrial age and the cities became industrial centers with a large population growth, mainly due to rural exodus caused by the onset of automation hand labor in agriculture, and improving the quality of life in cities with the arrival of light and lamp filaments surveyed by Sir Joseph Swan and Thomas Edison. The city, therefore, can be seen from different perspectives: the urban space that is composed of the material elements, and the social, the experiences and urban practices. In the words of sociologist Inaê [3], the city can be defined as follows: "more than an architectural or geographical fact the city is a social phenomenon, a production—and also a producer—of human collective activities. More than all the buildings and roads, the city is home to each of its residents, is that one social space in the world because it houses the individual routes and the smaller centers of social life, those most economically significant: family, close friends, loves".

1.1 Social Representations to the Organization of the City

According Jodelet, there is always the need to be informed about the world around us. In addition to adjusting to it, we need to know how to behave, physics master it and intellectually, identify and resolve problems that arise: is why we created representations. Faced with this world of objects, people, events and ideas are not (only) automatic, nor are isolated in a social vacuum: we share this world with others who serve in support, at times in a convergent way, others by conflict, to understand it, manage it or face it. That is why the representations are social and so important in everyday life. They guide us in the way of naming and jointly define the different aspects of everyday reality in the way of interpreting these aspects, makes decisions and eventually position yourself in front of them defensively [4]. For the author, the social representations are complex phenomena always enabled and action in social life. As a phenomenon full of riches, we found many elements (some, studied in isolation): informational, cognitive, ideological, normative, beliefs, values, attitudes, opinions, images, etc.). However, these elements are always organized under the guise of a knowledge that says something about the state of reality [4]. It is recognized that the social representations—as interpretation systems that govern our relationship with the world and with others—guide and organize behavior and social communications. Similarly, they are involved in various processes such as diffusion and assimilation of knowledge, individual and collective development, the definition of personal and partner's identities, expression of groups and social transformation. As cognitive phenomena, involves social belonging of individuals with affective and normative implications, from the experiences of interiorizações, practices, role models and thinking, socially inculcated or transmitted by the media, that it is connected. From this point of view, the social representations are addressed concurrently as product and process an appropriation of activity of external reality to thought and psychological and social development of this reality [4].

To Mumford, it is possible to understand the space of a city only when you know the culture that developed it (social representations). The author states that the more you know the culture of a city, the more will be able to understand the development of this city. In the words of historicist and archaeologist Ulpiano Meneses: "The culturally qualified city is good to be known (at local, the tourist, so there is business to attend to, the technical etc.), good to contemplate aesthetically fruída analyzed, suitable for memory, consumed affective and their identities, but it is also good to be practiced in the fullness of their potential. It must be good as a city, need conditions of economic viability, infrastructure, adequate housing policies, transport, health, education etc." [5]. Therefore, the city is more than an urban and architectural space is the place where they develop social representations, is the "home". In the words of Lynch, the city is: "Characteristic and legible environment that offers not only security but also enhances the depth and potential intensity of human experience. Although life is far from impossible in the visual chaos of the modern city, the same daily action could take on a new meaning if it were practiced in a clearer scenario. Potentially the city itself is a powerful symbol of a complex society. If well organized visually, it can also have a strong expressive meaning" [3].

This statement shows how the inhabitants of a city are faced with an urban landscape designed to offer the population greater identification and sense of belonging with their space, pride and memories, positive feelings of homeland only transpires when we are proud of environment to which we belong. Brancaglion [3] explains: "To understand a city, we must consider not only the city itself, but the way its inhabitants to realize". Thus, the deployment of street furniture equipment can contribute to qualify the image of cities, seen through its own inhabitants. In contemporary times, urban centers are specific scenarios of diversity and inequality. For this fact, it is necessary to think relational aesthetics [3] as an alternative to sociability, and perceive it as stimulating experiences as well as a device to solve the lack of social ties that a capitalist society and global causes. Confirming such statements, is quoted also Norberg-Schulz, which says: "There must be "identification" a "friendly" relationship with the environment. And both the guidance and the identification are aspects of an overall relationship. Thus, the environment is experienced as meaning bearer, "character is a correspondence between the external world and the internal world, body and soul" [6]. For some scholars, such as Brancaglion [3], social representations are categories of thinking that express reality. These concepts are closely linked to understanding the identity of meaning of space, i.e., what is concerned this study, which aims to explain the reasons why the environments and public spaces in cities suffer interference from street furniture and how esa relationship can be raw state in a positive and harmonious experience. For Brancaglion [3], "collective representations reflect the way the group is thought in its relations with the objects that affect it. To understand how society represents itself and the world that surrounds it, we must consider the nature of society and not of individuals".

The city is therefore a scenario full of overlapping messages that characterize the urban communication. This is defined by Nojima as the result of the interaction between social representations and the scenario where they occur. And it is through the interpretation of these messages that appear in the urban design of the city (streets, buildings, gardens, squares, furniture), the individual defines the elements that identify the city. According to the author, "the interventions aim to characterize the environment and this representation is a necessity that has the man to establish vital relationships in your environment to make sense of their actions" [3].

2 The Urban Space

Levi-Strauss defended the thesis that the urban space reveals the logic and underlying structures of a people. There would be inscribed right in order to have the houses of a village or a city. This ratio is not made aware by the villagers, but it can be discovered by the social scientist who is concerned with the study of specific culture and its forms of social and spatial organization. For the French anthropologist, the story itself is neither rational nor irrational value. There would be no logic inscribed in the cumulative time of a culture [7]. Barbosa et al. [8], the most concrete manifestation of urban place consists of uses and habits, to the same extent that place is the concrete manifestation of space. Thus, in general, the urban space is seen as an environment in which the human being, as a citizen or host, has a total freedom of movement where you can free interaction and uncontrolled between supposedly autonomous individuals. According to the author, the public space is understood based meeting in the presence of strangers who share the same environment, a space of collective expression, community, of being with and among others, celebration. It is also a universal space, completely freely accessible at any time and for any person. For Tschumi, the memory evokes feelings from the city's memory: "We have an innate ability to remember and imagine places. Perception, memory and imagination are in constant interaction; the sphere of the present merges with memory and fantasy images. There are cities that remain as mere distant visual images when recalled, and there are cities that are recalled in all its vividness. The memory brings back the pleasant city with all its sounds and smells and light and shade variations" [9].

The spaces of a city are perceived through symbols and signs that manifest themselves through objects, furniture, buildings, streets, squares, signs, stairs, parking lots, among others, that make up the identity of the place [3]. "The identity of a place is usually described by the image that people have of this place, of the resident population habits, their social representations and also of the interventions that it produces with the implementation of signaling equipment, furniture and even ornaments such as vases and plants. It is worth mentioning the existence of "private spaces for public uses" that are operated by private companies and not pre-determine a specific target audience for its use, such as shopping malls and hospitals. There is also the "public spaces for private use" as we find empirically, without organization, created by street workers and merchants, keepers of cars and prostitutes [3]". When you have in mind space "city" can not think of each element that is in a particular way, it should be reflected as a set of parts that complement and pervade a population. Each element has its value and contributes to building an environment in which the community and the city structure work social way [3]. Ferrara illustrates some of the major signs that are part of the urban area of a city: "The urban environment is a complex of signs: the formal (the very form of the built object), language (the street name), the advertising (posters), direction indicators, the aesthetic (the materials used, the stylistic features of facades, gardens, lighting etc.), contextual—the urban situation in which it is located (and the user signs)—the specificity of human behavior taken as a sign" [3].

In the same sense, we can mention Kings: "Cities need to provide for its citizens living spaces, leisure, integration and culture, so that men and women can exercise the right to collective use of 'living on the street or in the park with the family, the (re)value of human relationships, finally, the city must have in place spaces that offer quality of life. Citizens identify with places, as they recognize their importance, they assume the condition of collective use spaces and representing the local or global identity" [10]. So public space is one where, theoretically, you can find people of all social strata, cultural and economic, where diversity is one of its present characteristics. However, the current reality of the cities in shows another view, according to Beraldo et al. [10]. The loss and neglect of public spaces degrade the living relationship of individuals within these spaces, and thus there is a greater search for private entities to conduct such meetings. The apparent indifference of the State with the social spaces of the city has intensified since business groups have sought partnerships with the government to "gift" the city with works such as shopping centers, works with predominantly commercial character, which further accentuates uneven urban development. According to Harvey, "the common urban spaces should be designed so even for them to fulfill effectively their social role to the citizens. So there is an urgent need to make the citizens feel the characters themselves that space, capable of interfering in the city through their daily practices, even unconscious, as they have the right to the city" [10].

2.1 Urban Landscape

The "landscape" is a very broad phenomenon. It can be said that some phenomena form an "environment" for others. A concrete term for speaking environment is "place". In common parlance it is said that actions and events have a place. According to Schulz, when we refer to something more than an abstract location, think of a whole composed of concrete things having material substance, shape, texture and color. Together, these things determine an "environmental quality", which is the essence of the place or the qualitative phenomenon "total", which can not reduce any of its properties without losing sight of their specific nature, preventing the seats are defined by analytical or scientific concepts. For the author, phenomenology exists to solve this impasse, it is "a return to things" as opposed to abstractions and mental constructions [6].

Rodrigues, it states that the landscape is as a psychological resource and therefore a resource on human health. It is an indirect way, a resource of economic and material nature by the influence it has on certain activities such as tourism, residence and recreational activities. Research carried out over the landscape there is shown that [it] focuses powerfully on psychological functioning, as it can numb the most positive aspects of the subject's performance. The presence of a pleasant landscape for an individual can have a positive impact on their psychological functioning. The presence of a landscape can also generate reparative effects on the individual who is subjected overstimulation in the urban environment, particularly in large cities [11].

The spaces of a city or a neighborhood are perceived through symbols and signs that manifest themselves through objects, furniture, buildings, streets, squares, signs, stairs, parking lots, among others, that make up the identity of the place [3]. Mojina; Brancaglion The identity of a place is usually described by the image that people have of this place, of the resident population habits, their social representations and, above all, of the interventions that it produces with the implementation of signaling equipment, furniture and even loud as pots and plants. The importance of identity is reading it conducive to the individual, the possibility of appropriating the impressions that it will build in relation to the collective space, public, among others. Means for readability everything that can be read, deciphered and understood. To be readable, a city requires its spaces are conceived, designed to allow its inhabitants can interpret, recognize, as a whole, their neighborhoods, landmarks, roads [3].

3 Urban Furniture

The term "street furniture" can be used to define the objects used interactively in the urban landscape and its translation from English urban furniture and also the French mobilier urbain, communicate the idea of furniture or decoration of public space. According Creus, furniture word translates the idea of furnishing or decorating (Italian *arredo urbano*; *Arredare* = decorate). The utilitarian character is also part of the concept of "street furniture" for Montenegro, which defines elements such as articles directed to the convenience and comfort of users, especially pedestrians. The author states that the urban furniture makes up the environment in which it is inserted and is part of the design of cities, interacting with its users and the socio-cultural and environmental context [12]. One can also point out that the term furniture, even in the case of items included in the internal spaces of buildings, not only has a decorative character. In this sense, Freitas states that urban elements, or street furniture, are objects intended to equip the city and have allusion to home furnishings. The author emphasizes that "street furniture adds to the aesthetics and the functionality of the spaces, in the same way that promotes safety and comfort of users" [13]. Guedes prefers to use the term "urban equipment", as he believes that this concept also covers larger elements, intended for use in cities. In the author's view, street furniture is a subcategory of urban facilities. In order to standardize the terms used in discussions on the subject, Mourthé [14] states that in Brazil officially use the term "street furniture", and that therefore the most suitable to be used in the study.

This concept was born in the urban projects of the early seventeenth century, with the urbanization of the cities that was directly associated with ornamentation. It is understood by street furniture throughout the public service elements together to equip public spaces and roads, such as public phone booths, traffic lights, road traffic signs, lampposts, bus stops, newsstands and flower, benches, toilets, drinking fountains and also the elements that traditionally make up the urban landscape of cities like fountains, monuments, squares and parks. Some authors, such as Brancaglion [3] prefer to use the term "urban elements" to denote parts that make up interactively (or not) the landscape of cities. Brancaglion [3] adopts the same term of well differentiated from those, terming urban elements routes, boundaries, neighborhoods, crosses, the defining points of a city.

The street furniture helps to compose the image of cities and emphasize the city's identity in relation to other elements that make up the family of street furniture equipment of the city. It must be mentioned that the equipment family may also, through its design, help position, in time, the image of the city, making it more legible. This occurs when the individual can easily identify landmarks, neighborhoods or city roads, thus establishing a harmonious relationship between him and the world around them, without fear of disorientation or created by excitement or insecurity caused by urban environments. Second Basso and Linden [15], "the design of a city, and the elements that constitute it, is the materialization of their identity and cultural expression, political and socioeconomic". It can be said then that the city is composed of a set of elements that define the characteristics of a time and of a people. These elements can provide interaction, identification and reference to citizens of different ages and become the visual representation of the history of a people. In addition to the utilitarian aspect, street furniture complements the urban landscape and contributes to the cultural, political and socio-economic of the city where they live [15]. The idea of what is street furniture varies between authors and subjects. For common sense, it means the street furniture as those elements that contribute to the comfort and community recreational facilities such as banks, covers and other similar equipment. However, the concept is much broader, involving elements that allow the use of spaces, providing comfort, protection, services, information, laze, culture, etc. On this, Basso and Linden [15] defines: "The street furniture is located in the sectoral dimension, on the street level and can not be considered secondary, given its implications in the form of city equipment. It is also of great importance for the city's design and its organization for the quality of space and comfort".

3.1 Furniture and Its Relation to the Quality of the Urban Landscape

John and Reis [13] state that, in environmental awareness, it is worth emphasizing the importance of physical attributes and landscape meanings in the relationship between this and urban furniture, for the existence of a qualified landscape. An environment with quality refers to positive reactions from people who use it. The project area must be based on physical and spatial characteristics that meet people's needs. These characteristics define the environmental project quality built. The environment as said Lang, can be regarded as the neighboring "biological" people. In this conception are contained both natural aspects of the environment, and artificial features. For the author, all these elements, natural and artificial, comprise the "biogenic and sociogênico environment" with which the urban design relates. The built environment is an important part of the artificial world prepared by people to meet certain purposes, with different physical and aesthetic results [13].

For Lang, urban furniture, as a landscape component to be considered qualified to meet aesthetic requirements. Many people understand the aesthetics as something that varies for each person, although surveys show that it is possible to study scientifically and quantitatively aesthetic attributes, identifying patterns of preference [13]. In the approach to urban aesthetics, the perception of the landscape is influenced by formal and symbolic environmental attributes. The formal variables highlight the structure of forms, while the symbolic aspects emphasize its significance. Many authors, although not dismiss the importance of the symbolic aspects, emphasize the influence of formal features in perception and preference of individuals [13].

The development of projects related to the urban area, the challenge of the designer, according to Alexander, is the relationship between the city and its habits. "The man determines the need for new buildings (form) and the physical environment, provided by available land, provide a context for the shape of the city's growth" [3]. For Brancaglion, experience in solving a problem can not be typified as ideal and definitive, for any variable in the context can transform this solution into a new dilemma. In the case of urban furniture, this dilemma presents itself in the form of objects without any link to its surroundings, that is, developed with denominated features universal, but that does not fit in most environments in which they are installed [3]. Usually evaluates the street furniture alone in public space. However, it should be placed in the broader context of the city and not just as a decorative element. Is necessary to plan this criterion street furniture, paying attention to aspects of functionality, rationality and emotionality [16]. To John [17], there are six elements that should be considered in the choice of accessories for public places: function, durability, permanence, intensity of use, cost and location feature.

The relationship between the various elements understood as street furniture present in open public spaces usually alters the perception that people have of their own cities. Disregarding the functionality or the perception of the user population in the urban furniture design could do it does not fulfill its function or not being used properly, also hindering the use of the places where these elements were implemented [14]. Relating consistent with the surrounding elements and managed to meet the functions for which it was designed, street furniture can enhance the aesthetics of the landscape and provide greater satisfaction in the use of space by the community. Studies suggest that the implementation of urban furniture could contribute to visual pollution of the landscape, influencing the environment of aesthetic evaluation [3]. For Guedes [18], the street furniture projects need to be evaluated in an attempt to improve the quality of the created elements and improve the perception of the environment in which they were deployed. For Basso and Linden [15], however, the biggest challenge of the designer when designing this type of furniture is to find harmony between the uniqueness of the objects must be in the urban space and the aesthetics of the place where they will be inserted.

John [17] show that the improper disposal of elements on the sidewalks can be considered a barrier to the use of public spaces. In the City of London manual, Streets for All, is a series of recommendations on the implementation and design of street furniture in order to make attractive streets, safe and pleasant to users, since the preference of the people certain spaces is affected by, among other things, by urban elements. Some research also suggests that the furniture could significantly influence the preference of individuals for certain streets, as indicate John [17], for example, in study based on physical, visual and use, compared modern streets, traditional and renewed. According to the authors, the presence of street furniture could influence the use of such spaces is that negative ratings could be associated with the inadequacy of the elements to people's expectations. Similarly, the search results John [17] indicate that the existence of appropriate street furniture on the sidewalks could make the most significant environment for individuals to stimulate the social use of open spaces and, therefore, should consider not only the functional aspects of the elements, as well as the comfort of the users [17].

4 Final Considerations

Cities are home to endless urban practices that reveal the culture of its people and their preferences, habits and customs. Whether in relation to social habits or in relation to the use of practices and ownership of its streets, sidewalks and street furniture, the city reveals the cultural and identity component from its origin and reflects the setting and the environment created to represent the forces Community policies and the control. Similarly, the city is revealed from its spatial organization and as a contribution to social dynamics, offers urban facilities that suggest integration, identification, ambience, service and comfort to its residents. And integrate this spatial and urban planning logic as industriais structures project requires a technical and creative effort to qualify properly, public open spaces or closed, from implanatação this set of urban equipment which commonly are part of the urban landscape of cities. These structures should dialogue with its surroundings, allowing individuals to feel "at peace" with the city and the services that come of it, in order to provide a better visual comfort and a sense of organization and more appropriate belonging to man modern.

References

1. Mumford, L.: A cidade na história: suas origens, transformações e perspectivas. 4ª ed. Trad. Neil R. Da Silva. São Paulo: Martins Fontes, pp. 9–36 e 521–551 (1988)
2. Park, R.E.: A cidade: sugestões para investigação do comportamento no meio urbano. In: Velho, Otávio Guilherme (Org.). O Fenômeno Urbano. 2ª ed. Trad. Sérgio Magalhães Santeiro. Rio de Janeiro: Zahar Editores, pp. 27–67 (1973)
3. Brancaglion, R.L.: Equipamentos Urbanos, Design e Identidade Sócio-cultural: Análise e Proposta para a Cidade do Núcleo Bandeirante no DF. Dissertação de Mestrado, Universidade de Brasília (2006)

4. Jodelet, D.: As representações sociais. Org.; Tradução Lilian Ulup. – Rio de Janeiro – Ed. UERJ, pp. 17–40 (2001)
5. Meneses, U.T.B.: A cidade como bem cultural – áreas envoltórias e outros dilemas, equívocos alcance da preservação do patrimônio ambiental urbano. In: Mori, Vicotri Hugo et al (Org.). Patrimônio: atualizando o debate. São Paulo: 9º SR/IPHAN, pp. 35–76 (2006)
6. Norberg-schulz, C.: O fenômeno do lugar. In: nesbitt, K. Uma nova agenda para a arquitetura. São Paulo: Cosac Naify (2006)
7. Freitag, B.: Cidade dos homens, pp. 19–37. Tempo Brasileiro, Rio de Janeiro (2002)
8. de Barbosa, A.C., Castillo, L.A.G., Dantas, N.B. Artigo: O Produto do Espaço Urbano. 9º Congresso Brasileiro de Pesquisa e Desenvolvimento em Design (2010). 12 f. Disponível em: http://blogs.anhembi.br
9. Tschumi, B.: O prazer da arquitetura. Feminismo, gênero e o problema do corpo. Antologia Teórica (1965–1995). Organizadora: Kate Nesbit. Tradução Vera Pereira – São Paulo. Ed. Cosac Naif, pp. 573–583 (1984)
10. Beraldo, L., Jorge, L.P., Levitan, C., Sielski, I.M., da Silva, R.M.: Artigo: Design nos espaços públicos: um presente para a cidade. 9º Congresso Brasileiro de Pesquisa e Desenvolvimento em Design, 8 p. (2010)
11. Rodrígues, M.M.: El paisage visual. Estudios de Arte, Geografia e Historia. Málaga: Facultad de Filosofía y Letras, Universidade de Málaga, pp. 205–222 (1996)
12. Montenegro, G.: A produção do mobiliário urbano em espaços públicos: o desenho do mobiliário urbano nos projetos de reordenamento das orlas do RN. Dissertação (Mestrado em Arquitetura e Urbanismo, Universidade Federal do Rio Grande do Norte, Natal, 2005)
13. John, N., Reis, A.T.: Artigo: Percepção, estética e uso do mobiliário urbano. Gestão & Tecnologia de Projetos, vol. 5, no. 2, 27 p. (2010)
14. Mourthé, C.R.: Mobiliário urbano em diferentes cidades brasileiras: um estudo comparativo. Dissertação (Mestrado em Arquitetura e Urbanismo). Faculdade de Arquitetura e Urbanismo, Universidade de São Paulo, São Paulo, p. 280 (1998)
15. Basso, L., Van Der Linden, J.C.D.S.: Artigo: Mobiliário Urbano: Origem, Forma e Função. 9º Congresso Brasileiro de Pesquisa e Desenvolvimento em Design, 12 p. (2010)
16. Creus, M.Q.: Espacios, furniture y urban elements. In: Serra, Josep. Urban elements, furniture y microarchitecture. Barcelona: Ed Gustavo Gili, pp. 6–14 (1996)
17. John, N.: Avaliação estética do mobiliário urbano e do uso de abrigos de ônibus por cadeirantes. Dissertação (Mestrado) - Universidade Federal do Rio Grande do Sul. Porto Alegre, 210 p. (2012)
18. Guedes, J.B.: Design no Urbano: Metodologia de Análise Visual de Equipamentos no Meio Urbano. Tese (Doutorado em Desenvolvimento Urbano, Universidade Federal de Pernambuco) (2005)

Part V
Ergonomic Design, Assistive Technology and Accessibility

Colors in 3D

Lucia Regina Branco

Abstract People that have lived their childhood with a normal vision and in the adult age became blind don't find too much help in the industry of apparel. Once they knew colors and mind about what they're matching, it's an everyday challenge choosing what to wear so that they won't suffer prejudice at first sight of people able to see. Besides being a matter of fashion or good looking, separate which colors to put together inside the washing machine is also needed, so that garments keep their original appearance. Learning braille is an option, but it's not that simple for an adult—once literacy is an ability easier when done at the first years of childhood—and sensibility at fingertips is hard in many cases (mainly if blindness comes from diabetes), when talking about the small points that compose that language. This paper suggests a new way to help these persons with the quotidian task of choosing the colors of their clothes, using additive manufacturing to print cheap labels that can be recognized for those who learned to read the conventional alphabet and were used to write when they could see everything. Instead of trying to oblige fashion industry to include, it's a proposal to aid blind adults to help themselves. The study also suggests a design methodology approach applied to products manufactured by tridimensional printing, able to add virtual simulation and prototyping side by side with evaluation by people with special needs.

Keywords Assistive technology · Blind adults · Additive manufacture · Product development · Customization

---

Please note that the LNCS Editorial assumes that all authors have used the western naming convention, with given names preceding surnames (first name then last name). This determines the structure of the names in the running heads and the author index. No academic titles or descriptions of academic positions should be included in the addresses. The affiliations should consist of the author's institution, town, and country.

L.R. Branco (✉)
SENAI CETIQT, Rio de Janeiro, Brazil
e-mail: luciaregina@hotmail.com

M. Soares et al. (eds.), *Advances in Ergonomics Modeling, Usability & Special Populations*, Advances in Intelligent Systems and Computing 486,
DOI 10.1007/978-3-319-41685-4_38

1 Introduction

Losing the capacity to see in the adult age implies depending upon someone else to daily activities, and or make efforts to learn about organization, knowing by touch, memorizing, being attentive to the other senses. In the field of apparel, this research raised the hypothesis that after some decades wearing based on choices upon forms and colors, the person that becomes blind doesn't lose the interest on preferences acquired through life. This could be verified in the interviews made at Instituto Paranaense de Cegos—private non-profit association located in Curitiba (south Brazil)—when thirteen adults that were alphabetized and were able to see at least until they were teenagers

Instituto doesn't charge for any of the activities and the government offers a free bus to those who need to arrive there coming from distant areas of the city. Teachers are from public system and some of the courses are: orientation and mobility (mainly with external activities, which aims are teaching about the stick using a and new cares when walking), autonomous life activities (that intends to give independence related to washing machine, microwave and separating clothes), informatics (uses of cell phone and computer tasks), exercising and braille. The frequency is not controlled, and each class, even when made in group, tends to have a personal job, according to the needing and performance of each student. There's a constant rotation, new people arriving and others, after some months, leaving as they feel satisfied with what they've got as progress. The weather outside also influences in the number of persons. But at a medium account the institution had thirty students above eighteen years old in the conditions of external, in August and September 2015, when this study was made. Thirteen of those thirty were contacted and interviewed, using the following methodology.

2 Methods

Participative research with structured quiz, added to a practical test, were the methods used in this study. As it was assured by a representative of the Institute that studies considering the needs of their public are welcome, the researcher went there to talk with the psychologist, the director, and also some teachers. One student, present at her class during the first contact between researcher and a teacher, was also heard and her perceptions indicate that the first hypothesis had chances to be correct—it had four months she was blind and she had several difficulties in daily choosing her clothes. Based on the information, a quiz containing five questions was prepared, and also a rudimentary mockup was made to be used as a test with participants.

The mock up (Fig. 1) intended to be alike to what could be done in 3D printing, once proved its efficiency in helping people to identify their clothes. It was

Fig. 1 The mock up, manually done (*pictured over black surface*)

supposed to be used individually, put by the user in each cloth, eventually considering pairs (in the case of socks or shoes).

It was made in a white paper measuring 100.0 mm, in length and 40.0 mm in height. Characters measured 35.0 mm height and formed a word meaning a name of a color or a pattern. The letters were made by hand, with glue with sand over it. Colors and names of patterns, in Portuguese, vary by genders, and purposely it was written in both of them, to avoid a guessing game.

In the final part of the study it was used a prototype made by a 3D extrusion printer, in a size quite similar to the mock up, but with the relief of 3,0 mm, much superior to the one got with the sand. The purpose was make even easier to decode the words by touching.

Interviews and tests were all registered in video, with the authorization of the Institute and the participants.

3 Where the Idea Comes from

Some Design studies have tried to develop clothes, or other information about apparel, that can help blind people. This has been obtained using relief tags, or printing over the fabric, always considering the most known language among blind people that study in special schools: the braille. Created by Louis Braille, in 1827, it's a communication based on touch, composed by relief points which position is combined to identify each one of the alphabet letters, in order to compose the words, exactly as it's done in occidental alphabet. The most successful learning of braille uses to happen in the first decade of life, when one is born blind and gets instructions, beyond the job of awareness to touch the fingertips over the volume marked in the paper. It's not only in this language (braille) that best results of learning are obtained at the early childhood. Investigating the process of literacy, in 1965, Maria Montessori said that "it's needed to look up for the age in which mechanisms of written language are ready to be installed; and, then, they'll be made "without effort, naturally, causing pleasure and increasing vital energy" [7]. Criticizing the traditional school of those years, that used to lose the best moments to work on written language, she continues:

> It's not this, surely, what is seen in other schools; to tease the motor mechanism of writing they require from that tiny hand, now became adult because much of movements were fixed, the torturing effect almost deforming, of "making a reverse bleeding" in the evolution

> path. The hand of a six or seven years old child loses, in this way, its precious period of motor skills. This delicate small hand has surpassed the time when appraised to coordinate its movements: this period in which was "created" the "functional" hand, and there is it "condemned" to a heavy and unnatural effort! [7].

What the author defended – and until today is accepted by educators—is that there is a time of life, a specific age in which persons learn the required movements to written language with more resourcefulness because the corporal mechanism is still flexible, more sensible, more suitable to. That's the reason why learning how to write, at the age of seven years old, commonly has better results than literacy in adults. With braille language it's not different; to teach an adult to read braille is a hard task, with a few chance of fluency. To that hand that was not sensitized to recognize the small relief of that language in the more appropriate age sometimes it's needed to add a reduced sensibility brought by diabetes – a disease that in 75 % of the persons that have it for more than twenty years causes blindness, as estimated the Brazilian society of ophthalmology [2]. In adults that have diabetes mellitus over than 15 years it's possible to find some grade of retinopathy in 98 % of the cases, and this is the most common disease that lead to blindness in countries in development [6].

One of the most important contributions of Montessori to Education was the creation of sensorial learning material to literacy, that was the main inspiration of this research. Trying to develop sensibility to recognize the design of letters, she cut in sandpaper each letter of the alphabet, and she helped children guiding them to use their index finger to follow the sense of design, and after introduced a baton in their hands to follow the trace in the air. To develop the cropping Montessori had the help of available technology of that time: scale, pencil and scissors.

Inspired by this sensorial idea, this research considered that adults that loose the capacity to see, once alphabetized, could recognize letters, as long as they could catch their trace with a sense still functional. The researcher designed cards with words that meant colors or patterns (stripy and checkered, for instance) and composed a tactile relief with glue and sand over the trace of each word. To Montessori's conception it was added the volume, that could facilitate the perception by fingertips without too much training. The mock up was made thinking about the technology available nowadays—the 3D printing. As clothes need to go to washing machine (or bucket), stay in the chord to dry, and, after, stowed in hangers or drawers, any feature should face these conditions. So, the intention of the mock up was only make a preliminary test; it needed to be a volumetric model in the was it'd be used, with the conditions projected to the final artifact.

Think about printing the card was a condition based in principles of manufacture's project, as taught by Bralla [2]. Some of his lessons are fundamentals to any manufacturing, but once designing to the base of pyramid—and disabled are frequent poor people, as emphasizes Plos et al. [10]—it's mandated to consider simplicity and the need of using shelf materials. The filament used in this project is a commodity, as also became some of the machines that extrude them, and it's exactly this characteristic that have made true several process of development of orthosis, prosthesis and resources that are able to help people who need assistive technology, as presented by Ostuzzi [5] and several authors that use the benefits of customization, and/or small-scale, and/or the low costs of 3D printing. Project and redesign has become a workaday task, and in the participative research—that bases on assumption that when coming back to the community an upgrade in the artifact or situation is presented—that was a qualitative gain. As teaches Jacobs, a basic advantage of using a prototype is that "there's no better way of certifying that a complex component has every wished characteristic than holding it in the hand, turning it sometimes and look at it in all its angles" [10]. In the case of blind people interviewed, the prototype could be repeated and improved as long as it was needed, because printing a concept is feasible, a fact not imaginable when casting was essential. This was, though, a guide to the study.

4 Discussion

One of the questions of the quiz investigated if there were changes in the way participants used to dress—like colors and patterns—after blindness. In 77 % of the cases it was found there are modifications. Some positive, others no so. Moises didn't use to wear stripy shirts, and in the day he was interviewed he was wearing a striped one. Chosen by his son, that garment represents a novelty in his wardrobe, which access was facilitated because the guy said that clothing fitted quite well to his father. This is one of the cases in which it's possible to identify the habits change in persons that face blindness after became adults. But not all the stories bring good situations. Cynthia, in the opposite way of Moises, realized that choices concerning clothes have to be done in function of convenience for the moment of wearing, washing or keeping them organized, daily, as she tells:

> Cynthia – *So, like this, I have my socks with puppies, little princess, but the rest is generally white or black, quite basic. It's that: blind people, normally, when he starts, not when he loses, but after he's sometime* [without the capacity of see]*, and he's going to buy things… I think it's very much… At least myself, I go by convenience… Every white ones have approximately this size, the tube like this, the black ones have something different, you see? Generally, I do this…*
>
> Researcher – *You're creating methods to organize yourself.*
>
> Cynthia – *Yeah. Easy, it's not, as I told you. You put the garment… Then you talk… Will that work?* [laughing] *Because sometimes you have no notion, isn't it? It's like this, you put something, put such a thing… That's why I say… After we lose… When we have some vanity and loose the vision, it becomes hard, I think this gets us very depressed…*

The tactile memory is what helps a blind person to define his clothes. It's also a lesson of the teachers in the Institute: find out some sign, a characteristic in each garment to memorize what it is. At the time people are able to see, they make choices according to their interest in pleasing—themselves or others—, chocking, causing provocative effects, and it's a daily exercise of form, texture and colors. As people give different importance to these items, it was asked to participants if combining colors was important to them, giving a grade between one and ten to this question. The average is near seven. This can suggest that there's something more than simply check if one color match with other, and beyond any notion of fashion, as Fraser [4] explains:

> The act of living something comes before reacting to it. Some can see colors, others see them differently than the majority, but generally our eyes work in the same way, and the same stimulus produces the same answer in people's visual system. What happens after that is another question. Once our eyes allow us to experience a color, it's all the rest of us that decides the meaning we lend it. [4].

When an adult loses his ability to differentiate colors he starts to count upon others, and also with a constitution of new values or strategies, as memorizing the tactile sensation or a signal in a garment. Going to a shop to buy clothes is a task that only 8 % of interviewed make by themselves. 46.15 % of them count on the help of someone that lives together, 23 % with someone that doesn't live in the same house, and 23 % ask for the help of both, people outside home and someone that lives together. To daily separate the clothing, they're going to wear, 54 % of the participants declare they make it by themselves, while 31 % are helped by someone who lives together. 15.38 % make the task with someone who lives in the same house.

Store the garments that come dried is another challenge, because it depends on it the subsequent organization of daily wear. Only 31 % of the interviewed tells they leave this task to someone who lives in the same house, and 7.69 % said they make together with that person. 61 % of the sample say that stow by themselves.

With these high percentiles of persons who became blind after being adult trying to learn how to be independent, it was evident the need of some resource able to help, somehow, the strategy of differentiate by color, if not as a matter of preference, at least for some exigence—the case of the washing machine, that doesn't forgive mixing white and colors. So, the card with the name of the color was suggested for this reason. 38 % of participants didn't identify the word, represented by the word "BRANCO" (white, in Portuguese). To some of those who recognized the first word, it was presented the word "LISTRADA" (stripy, in Portuguese), and it was successfully read. 12.50 % of these 62.54 % that comprehended the word declared they wouldn't use cards with identification in garments.

After the interviews and tests it was provided the first printing of a prototype (Fig. 2), in order to test, with the same participants, the concept.

As there's a lot of turnover at the Institute, it was possible to make only one checking, coincidently with the same participant that made the pre-test of the quiz and who gave the first information, in the phase of identifying essential problems, in July, 2015. Neiva's evaluation (Fig. 3) about the card printed by extrusion was:

> Researcher – *What about the label, for you, the handling, put it in the cloth, what do you think? If you'd have to put in the garment to store it in the drawer, or in the hanger, or in the washing machine…*

> Neiva – *Inside the washing machine I don't know how much this can damage the fabric, because of its… It should be improved this…* [showing the corners] *Make a round corner,*

Fig. 2 The 3D printed label, with an alligator clip

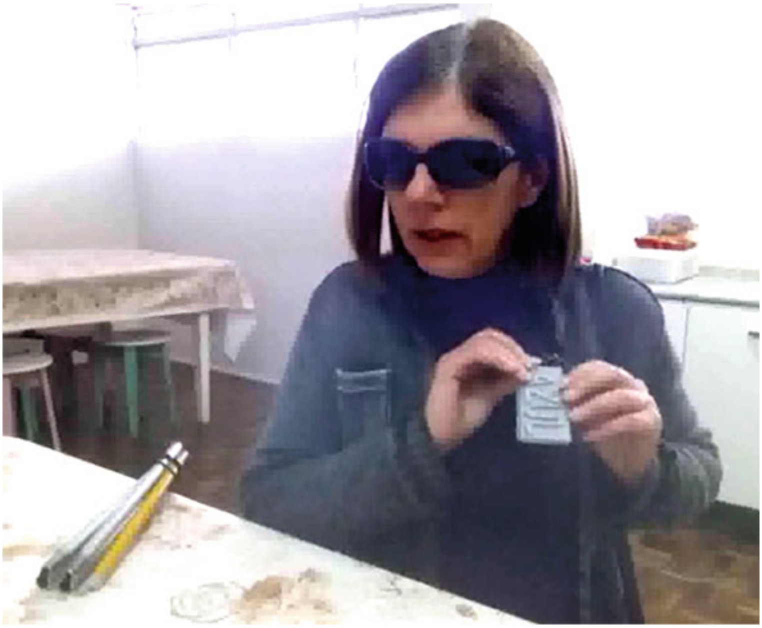


Fig. 3 Neiva, giving feedback while testing the label

that doesn't catch, because this one it wouldn't be possible, unless it was just denim, or only cotton, 'cause in such a garment [showing her knitted blouse]*, at the time the machine works it's gonna rip. This clip, also, it must not have this… Here…* [showing the burr].

Researcher – *Burr*.

Neiva – *This* [now referring to the alligator clip] *also is going to rip in knitted garments. The system really attached, it's really steady, I believe it's not going to get out inside the washing machine. We can look for a strategic place to put the label, isn't it? I can remove it and put it inside the sleeve, so that when the machine works it's the outside that's going to be touched, in the inside we don't have the risk to be loosen, the only problem is the…*

Researcher – *Finishing.*

Neiva – *There should be a material that gets rounded, the corners…*

Researcher – *This is easy to solve…*

Neiva – *But the label itself, here* [showing the borders], *it's smoother, more polished… Because not too much, because it has to have… This texture is great to touch, to those that know, that once knew letters, it's not difficult to identify.*

Researcher – *Can it be smaller?*

Neiva – *Yes, it can be smaller. Not too much, I don't know if anybody can recognize a smaller letter, but like this is cool. I think the idea is valid. From my point-of-view it's valid.*

Researcher – *Would you be willing to put and take off of clothes, every day, to know what you're stowing, what you're wearing…?*

Neiva – *Sure! No matter how much… Many blind people work, but they don't work full time so that they don't have time for anything…. Many of us what we have the most is time! Don't you think? Me, for instance, nowadays what I have the most is free time. Put and taking off the label, in the washing machine, think what a therapy!* [laughing]

Neiva's honest perception shows how additive manufacture can push changes in the first conception defined in the beginning of the process of planning and designing. To Pahl and Beitz [9] the phases of the evolution were linear, they started with a requirements list, followed by a concept; then, a preliminary layout was done, and, at last, a definitive layout. 3D printing makes this phases interpenetrate themselves, and even after the conceptual project it's always time to come back to clarify the task and come back to requirements list, because if a new group bring different ideas they'll be welcome, because it's still useful to change the project, even if it's in a commercial phase. This happens because there's no tooling to be wasted, no cast to be paid back when additive manufacture is used.

The labels were intentionally made in both genders (for words that have two genders, in Portuguese), so that the participants couldn't be sure if they were written in masculine or feminine unless they got till the end of each word. But the successful beginning of identification made, in every cases, that the decoder tried to find out the rest of the word by guessing. Specifically, in the case of colors there's a minimal difference, so that the idea of reducing the model seemed to be feasible, as the decoding process is—among people that see and also among blind participants—a natural pattern of the brain. In every cases when reading was successfully done the end of the word always resulted in a guessing game. Representation by symbols or even in braille can also be used in these kind of 3D printed labels.

It's important to mention that the artifact that was created in the study Colors in 3D is not the only resource to help blind people, and it cannot be the best.

Available for free, the app "Camfind" has the intention to help those who need to help not only color, but also objects. All the users need is a smartphone with internet and voice synthesizer. When the camera is pressed it sends the picture to a server and in some seconds it returns the information. Quite simple, it depends on someone used to smartphones. It's March, 2016 and the app "Be my eyes" also gets many blind users connected to real people available to help, at the other side of the line, but not yet in Portuguese and not for all smartphones' system. The embroideries were also mentioned as an interesting alternative, but they have a higher cost, about four dollars per unit. The 3D printed artifact developed in this study—without considering it could be done with a cast—had its cost less than one dollar.

At this point, in September 2015, what is possible to say is that the resource presented in Colors in 3D had its utility by more than a half of the sample; it has a low cost (from the point of view of the final customer), and it's customizable. Some years ago it was discussed the possibility to use electrical trigger—a videocam with electrodes—to generate sign that blind people could convert in colors; differently from the study made by this study made by Hurvich [5], the proposition here is a reality, with hypothesis validated by a mock up and a prototype. It's the kind of case that evidences the application of additive manufacture, that qualifies and distinguishes it as an increment in the process of planning and development of products, like emphasizes Volpato "what before was a specialized and time-consuming task became easier, and became responsible by the use of prototypes in PPD" [11]. Beyond the fact that it's easy to make, it cheap. Something that the economic situation of the country and blind people, mainly, requires.

5 Conclusions

3D printed labels can be an useful resource for blind people, considering the fact that they can go inside the washing machine, and allow the identification of any garment, with only the first help of identifying it for the first time, and after each use, caring about putting again the label before storing or washing. It helps in an independent quotidian, no matter if the blind was born in this condition, or if he became blind after been alphabetized. This because the labels as described in this study can also be used to identify more items beyond colors, like size or store organization that allow adults to help themselves, and they can be printed in any language, no matter if braille, Chinese or Hebraic.

Suggestions to future studies

In conversations with participants of the study and also among people that are able to see, the use of some signs and codes that could be shorter than words used was discussed. Drawings that could represent the patterns, as stripy or plaid, were also a suggestion, and this can be thought for a future study.

Acknowledgments The opened doors of Instituto Paranaense de Cegos were essential to this study, so, it's essential to thank people who work there, mainly to teacher Lilian, and all the participants of the research. NUFER (Núcleo de Prototipagem e Ferramental), from Universidade Tecnológica Federal do Paraná, also collaborated in 3D modeling and printing, carefully supervised by internships Rodrigo Pulido Arce and Yvi Mori, to whom special thanks are made also because of their participation in discussions that enriched the development of the artifact.

References

1. Albers, J.: A interação da cor. Martins Fontes, São Paulo (2009)
2. Bralla, J.G.: Handbook of Product Design for Manufacturing. McGraw-Hill, New York (1999)
3. Conselho Brasileiro de Oftalmologia. Retinopatia diabética, http://www.cbo.net.br/novo/publico-geral/retinopatia_diabetica.php
4. Fraser, T., Banks, A.: O guia completo da cor. São Paulo: Editora Senac (2007)
5. Hurvich, L.M.: Color Vision. Sinauer, Massachussets (1981)
6. Juárez, S.R., Castillo, A.S.: Oftalmología. Mexico: Editorial El Manual Moderno (2014). http://site.ebrary.com/lib/pucrio/reader.action?docID=10853750%23
7. Montessori, M.: Pedagogia cientifica. São Paulo, A descoberta da criança. Flamboyant (1965)
8. Ostuzzi, F., Rognolli, V., Saldien, J., Levi, M.: +TUO project. Low cost 3D printers as helpful tool for small communities with rheumatic diseases. Rapid Prototyping J. **21**(5). (2015). doi:10.1108/RPJ-09-2014-0111
9. Pahl, G., Beitz, W.: Engeneering Design: A Systematic Approach, 2nd ed. London: Design Council (1999)
10. Plos, O., Buisine, S., Aoussat, A., Mantelet, F., Dumas, C.: An universalist strategy for the design of assistive techonology. Int. J. Ind. Ergon. **42**, 533–541 (2012)
11. Volpato, N. (org).: Prototipagem rápida: Tecnologias e aplicações. São Paulo: Blucher. (2013). (2nd reprint)

Palmar Pressure and Perception of Discomfort in the Use of Axillary Crutches

Gabriel Bonfim, Danilo Silva, Erica Neves, João Plácido, Ana Mantova, Fausto Medola and Luís Paschoarelli

Abstract The use of crutches is mainly related to healing processes after injuries or/and surgery of lower limbs. The design of the handle grips may influence the pressure distribution on the palm of the hand and it can influence the perception of discomfort. This study was aimed to verify whether different handle grip diameters influence the pressure distribution in the palm of the hand, as well as the perception of discomfort in the use of axillary crutches. It was used the Grip System Versatek (Tekscan Ink) and a Hand Map protocol to evaluate those variables. Results showed that each region of the palm of the hand was affected differently by each handle grip. There was no pattern for the distribution of pressure and the region with the highest number of occurrences of discomfort did not always attribute the highest degree of perceived discomfort by the subjects.

Keywords Ergonomics · Design · Axillary crutches · Pressure mapping · Discomfort

G. Bonfim (✉) · D. Silva · E. Neves · J. Plácido · A. Mantova · F. Medola · L. Paschoarelli
PGDesign - Univ. Estadual Paulista - UNESP, Av. Eng Luiz E. C. Coube.14-01, 17033-306 Bauru, Brazil
e-mail: gh_cb@hotmail.com

D. Silva
e-mail: danilo@idemdesign.net

E. Neves
e-mail: ericapneves@yahoo.com.br

J. Plácido
e-mail: joaocplacido@gmail.com

A. Mantova
e-mail: anamantova@hotmail.com

F. Medola
e-mail: fausto.medola@faac.unesp.br

L. Paschoarelli
e-mail: paschoarelli@faac.unesp.br

M. Soares et al. (eds.), *Advances in Ergonomics Modeling, Usability & Special Populations*, Advances in Intelligent Systems and Computing 486,
DOI 10.1007/978-3-319-41685-4_39

1 Introduction

Axilar crutches are one of the common mobility aids and they are widely used throughout the world. They are a practical alternative to improve balance and relieve body weight supported by the lower limbs. The use of crutches is mainly related to rehabilitation processes after lower-limbs injuries and/or surgeries.

The design of this kind of crutch consists in a handle grip and a pad that rests under the axilla. Both elements are positioned in order to help the development of a periodic oscillation of the legs and the crutch along with a continuous displacement of the body in the plane progression [1].

In this activity the body weight on lower limbs are relieved. However, the upper extremities become weight-bearing structures [2], which can imply in several complications such as: compression of the radial nerve due the axillary pad [3]; irritation/injury in the elbow and shoulder joints due the large reaction forces that may arise at initial contact [4]; and other impairments regarding the long-term usage of such device.

Hence, the locomotion with axillary crutches requires a hand grip exertion to compensate the body weight that should be on the lower limbs. This action involves the application of stressful and repetitive forces that can contribute to the appearance of lesions and localized fatigue [5]. The risks associated with the use of axillary crutches has led researchers to develop investigative studies to understand better the biomechanical response in this kind of motion.

Some studies have evaluated the loads of the upper limbs [6, 7], ground reaction forces [1, 4] and forces applied on handle grips [8, 9]. However, studies investigating the pressure mapping on hand-handle interface are scarce.

The handle grip design can influence the pressure distribution on the hand palm, and therefore generate restrictions or lesions in this anatomical area of users [10]. Therefore, such aspect is important to be investigated as it can influence the pressure distribution as well as the perception of discomfort.

Hence, this paper aims to investigate if different handle grip diameters influence the pressure distribution on the hand palm, as well as the perception of discomfort during a simulated ambulation activity with the aid of axillary crutches.

2 Background

The hand grip during the use of axillary crutches exposes the user to reaction forces in the hand palm, which can be associated to constraints and lesions due the high pressure in located points of the hand [11–13]. This pressure compresses arteries, veins and nerves and can cause inflammation, calluses and other injuries that can be irradiated to other anatomical regions of the hand [10, 13].

Some researchers have associated Carpal Tunnel Syndrome (CTS) with the long-term use of axillar crutches, since the reaction forces on the hand palm increase pressure inside the carpal tunnel [10, 14, 15].

The pressure on the hand is not equally distributed and the handle grip shape influences the maximal grip force, the grip force distribution and the finger joint postures [16]. Therefore, the characteristics of the handle grip, such as texture, size, material and shape influence the pressure distribution as well as the perception of discomfort.

On a previous study with three different handle grips for axillary crutches, [17] it was verified that a handle grip with anthropomorphic shape lead to higher pressure levels on subjects hands, when compared to cylindrical ones. Two cylindrical handle grips with different textures produced the same output pressure. That study also showed that the pressure level might vary between hands (left and right).

The ergonomic design research also approaches the user perception about the object [18]. One of the most common criteria used for product evaluation is the comfort/discomfort. Comfort does not have a precise definition, it depends on the purpose of the study, but it can be thought as a pleasant state or relaxing of the body related to the environment [19]. Hence, comfort is an ergonomic quality, which is desired by the user [20].

Looze et al. [21] suggest a theoretical model, which assumes that the comfort and discomfort are independent, and not opposing factors on a continuous scale. However, under the influence of emotional factors, discomfort may become comfort. The authors also suggest that comfort is associated with feelings of relaxing and well-being while discomfort is associated with pain, fatigue or numbness.

Through time, researches, regarding the manipulation of objects and perceived comfort or discomfort, presented different assessment methods. On a study, two models of scissors were evaluated, a conventional one and another with an ergonomic design [22]. The study involved 44 hairdressers that used both models and filled a hand map protocol, where anatomical regions were indicated according to the perceived discomfort during the task. They noticed that the conventional scissors caused discomfort in a larger number of users.

Similarly, Groenesteijin et al. [23] compared three models of pliers: two conventional models and a multifunctional one. The study was conducted in a workplace as well as in the lab to compare results. The hand palm was divided in eight regions to evaluate the intensity of discomfort on the contact areas of the object. The results indicated more intense discomfort for both conventional models, when compared to the multifunctional one.

3 Background

3.1 Materials

To assess the handle grip diameter influence on the pressure distribution, three cylindrical handle grips were made. The first one was 20 mm (H1), the second one 32 mm (H2), and the third 40 mm in diameter (H3). All handle grips were 100 mm long and made of PVC pipes with hardboard inserted to make them fitable to a standard axillary crutch. These handles and their technical details can be seen in the Fig. 1.

A pair of axillary crutches was used. Figure 2 shows the pair of axillary crutches used in this paper.

To measure the pressure distribution on hand palm, the Grip Versatek system (Tekscan Inc.) was used. The sensors were placed on a textile glove to be easily attached to the subject's hands. Figure 3 shows the complete system attached to a subject.

In order to detect and analyze the areas where each subject indicated discomfort, it was used a study [24] which divided a hand in 33 regions, using a map to better systematize and understand data. For each region a letter (A–Z) was assigned, the side regions from the distal phalanx of the index finger to the thumb, received apostrophe, separating them from their larger areas (Fig. 4).

Fig. 1 Handle grips used in this paper and their technical characteristics

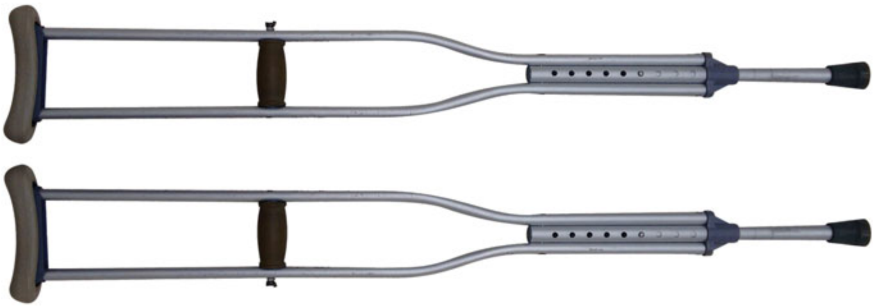


Fig. 2 Pair of aluminum axillary crutches (Mercur)

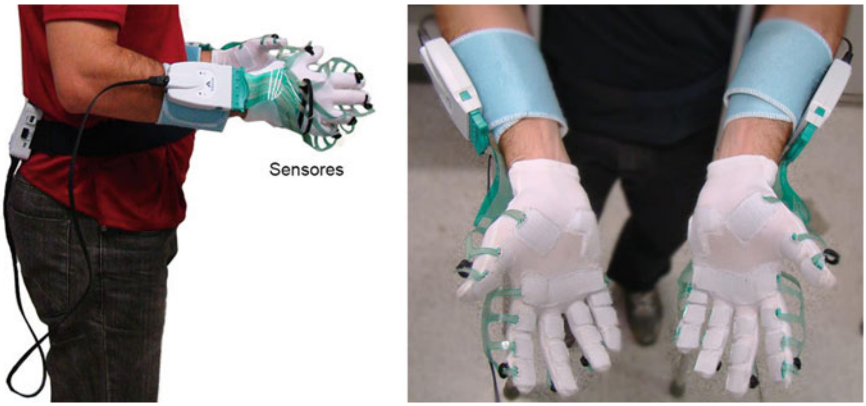
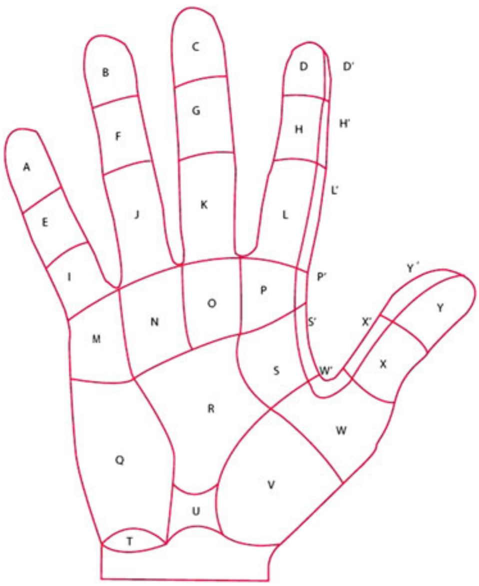


Fig. 3 Grip Versatek system coupled to a subject [17]

Fig. 4 Hand map protocol used to evaluate perceived discomfort [24]



3.2 Sample

Eleven young male subjects participated in this study. The mean age was 22.3 years old (s.d. 2.1 years). All subjects reported themselves as right-handed and no subject reported any musculoskeletal symptom and/or lesion in the upper limb up to 12 months prior the activities. Only one subject had prior experience with crutches for a very brief time.

3.3 Experimental Procedures

All procedures took place in a room at UNESP campus Bauru/SP/Brazil. All subjects were approached individually, filled an Identification form and signed an Informed Consent form. Participation in the activities was voluntary. A Research Ethics Committee (Protocol 800.500/2014—CEP/FAAC/UNESP) approved the procedures.

The procedures were explained and demonstrated to all subjects before the activities. The subjects were asked to take both feet off the ground during the steps, bearing their whole body weight on the hands/handles, in a three-point pattern. Since it is not recommended to bear the body weight at axillary pads [25], the researcher explained how the body weight should be supported during locomotion.

The activity (Fig. 5) consisted in taking five steps forward, following a straight line marked on the floor. The path had a sign on the start, but the end depended on the length of the steps, which varied per subject. There was no time limit or pace imposed to the subjects, they had performed the steps at their own pace.

After the instructions, the subject put on the gloves with the Grip system and the height of the crutch was adjusted. A random pair of handle grips was coupled to the

Fig. 5 Subject performing the steps with an axillary crutch

crutches and the subject was asked to go to the start point of the line and start moving only after a verbal command. After the start, the subject took five steps and then stopped. The research software recorded the pressures during the locomotion.

After completing the five steps, the subject sat at a desk and filled the discomfort protocol for the first handle grip. This protocol has two sequential stages: in the first one, the user marked dots on the hand areas in which he perceived any level of discomfort; in the second one, a plastic sheet with the hand regions was imposed to the filled form and then the subject assign a discomfort level to the hand regions with dots (from 1—some discomfort, to 5—extreme discomfort).

After fulfilling these stages, the subject repeated the procedures with the remaining handle grips. All procedures were recorded with a GoPro Hero 3 camera, which allowed analyzing the movement and eliminating noise or errors in data collected.

3.4 Data Analysis

The pressure on hands was acquired for all the 17 regions of the Grip system, but for practical reasons they were grouped into five macro regions of the hand: thumb, fingers (fingers 2–5 act in a similar way), metacarpal, thenar and hypothenar regions. Figure 6 shows the macro regions of the hand analyzed in this paper.

The first and the last steps taken by the subjects were not considered in data analysis. The subjects were not experienced with crutch locomotion and they could lost balance in the beginning or braking part of the activity.

The pressure values were then exported from the Research software to a spreadsheet (Libreoffice Calc 4.0). For the purpose of this study, an average value for each region for both left and right hands was calculated. Data was analyzed with

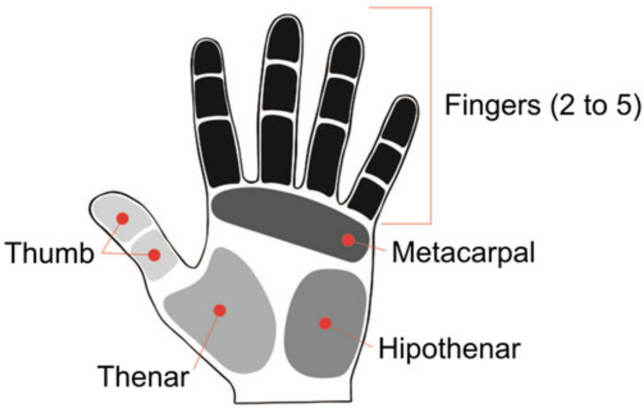


Fig. 6 Hand regions analyzed in this paper

descriptive and inferential statistics. The data sets had normality (Shapiro Wilk's W test) and homogeneity (Levene's test) checked in order to select the appropriate comparative statistical test.

If the data was normal and homogeneous, the Student's t test for paired samples was applied; otherwise, the Wilcoxon's matched pairs test was applied. All comparisons were made on IBM SPSS 22.

Data from the hand map protocol (discomfort areas and their rates) was registered on spreadsheets as well and analyzed by descriptive statistics. Each region has an associated number of points, which represents the counting of times it was marked as an area of perceived discomfort, and an average score for the discomfort rate.

4 Results and Discussion

Data analysis allowed identifying the pressure levels on each macro region of the hand. The results (Fig. 7) show that there were no differences between the pressure over the thumb for H1 and H2 handle grips (Wilcoxon, $Z = -0.898$, $p = 0.369$). For both of them the pressure was around 30 kPa. The handle grip H3 showed a higher pressure when compared to H1 (Student's t test, $t(32) = -4.491$, $p = 0.000$) and H2 (Wilcoxon, $Z = -4.217$, $p = 0.000$).

For the fingers region, handle grip H1 showed significant higher pressure when compared to both H2 (Wilcoxon, $Z = -4.527$, $p = 0.000$) and H3 (Wilcoxon, $Z = -2.279$, $p = 0.023$). For H1, the pressure was around 40 kPa and for H2 and H3 handle grips, the pressure was around 35 kPa. There were no differences between the handle grips H2 and H3 (Wilcoxon, $Z = -1.191$, $p = 0.234$).

The analysis of the pressure over metacarpal region showed that the pressure with the use of H2 was 38 kPa, which was significantly lower than both H1 (Wilcoxon, $Z = -2.815$, $p = 0.005$) and H3 (Wilcoxon, $Z = -2.016$, $p = 0.044$). There were no differences between the handle grips H1 and H3 (Wilcoxon, $Z = -0.599$, $p = 0.549$).

For the thenar region, the pressure was around 30 kPa. The H1 handle grip showed significant lower pressure than both H2 (Wilcoxon, $Z = -2.753$, $p = 0.006$) and H3 (Wilcoxon, $Z = -2.423$, $p = 0.006$). There were no differences between the handle grips H2 and H3 (Wilcoxon, $Z = -0.031$, $p = 0.975$).

The pressure over hypothenar was around 35 kPa. The comparisons showed that there were no differences among any of the handle grips analyzed.

The results, regarding the perceived discomfort of the activity, showed that, for the right hand, most extreme regions of the hand exhibit no discomfort at all. The Fig. 8 shows how many times each region of the hand was marked with any level of discomfort for each handle grip analyzed.

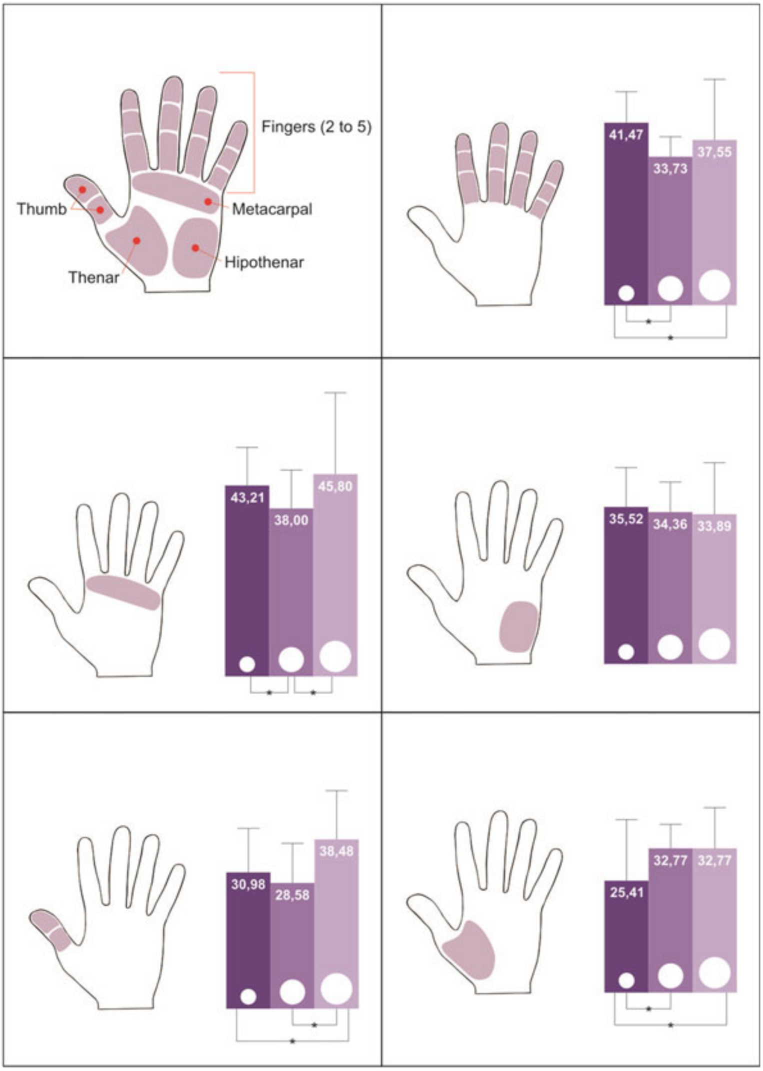


Fig. 7 Pressure distribution over the palm of the hand with the use of each handle

The handle grip H1 exhibited more points on thenar and hypothenar region, as well as the medial phalanx of the fingers three to five. H2 shows more discomfort on thenar, metacarpal and proximal phalanx, and for H3 the records are

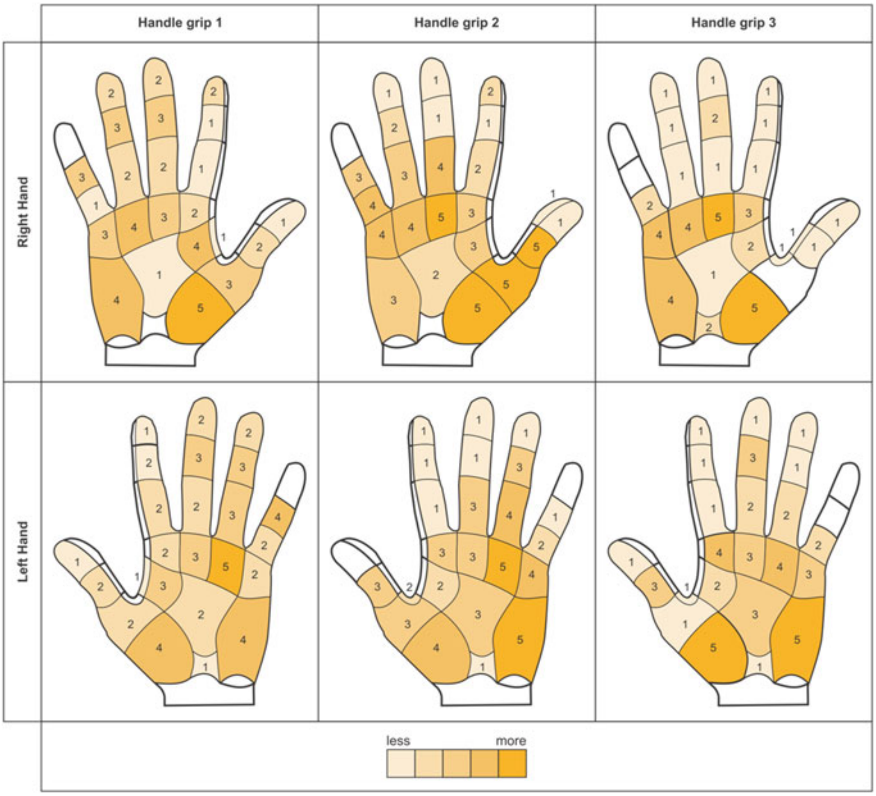


Fig. 8 Number of times each region of the hands was marked with any level of discomfort

concentrated on thenar, metacarpal and hand palm as a whole. The total sum of occurrences for H1 was 55, for H2 was 65 and for H3 was 43.

For the left hand, similarly to the right hand, most of the extreme regions exhibit no of discomfort. Figure 9 shows the level of discomfort over the palm of the hands.

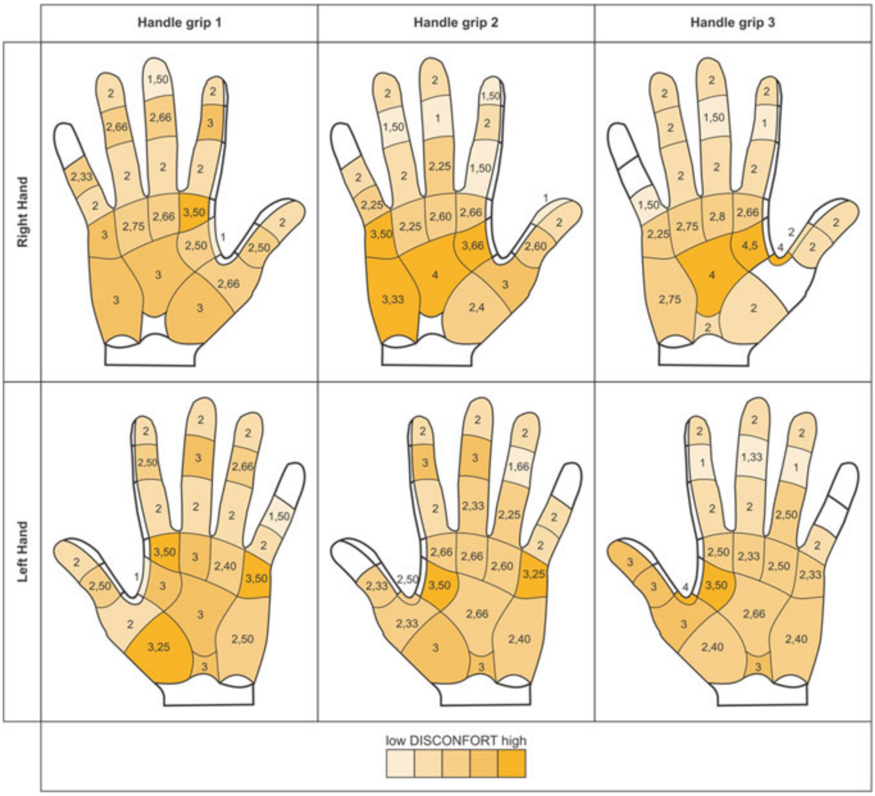


Fig. 9 Mean values of discomfort rate for each region of the left hand

5 Conclusion

This study allowed analyzing how each region of the hand palm was affected differently by each diameter of handle grips. Data analysis allowed identifying the pressure levels on each macro region of the hand. Regardless of the diameter of the handle grip, the metacarpal region suffer more pressure. Fingers and hypothenar regions presented higher pressure during the use of the handle grip with the smallest diameter. For the metacarpal and thumb regions, the highest-pressure ratings were related to the handle grip with the biggest diameter.

The results, regarding the perceived discomfort of the activity showed that, for both hands, most extreme regions exhibit no discomfort. The quantity of discomfort reported by region is not related to the degree of perceived discomfort by region, in other words, the region with the most occurrences of discomfort did not always attribute the highest degree of perceived discomfort by the subjects. The highest degree of discomfort was attributed to the right hand.

Studies of this nature collaborate with the development of products focused on the ergonomic design that aim quality of life for users, especially when it comes to a product of assistive technology that still can improve its design quality.

Ackowledgments The authors would like to thank CAPES (Coordination for the Improvement of Higher Level Personnel) PGPTA 59/2014—Project 10) and São Paulo Research Foundation (FAPESP—Proc. 2013/24629-5) for the financial support.

References

1. Shoup, T.E., Fletcher, L.S., Merrill, B.R.: Biomechanics of crutch locomotion. J. Biomech. **7**, 11–19 (1974)
2. Lighthall, H.L., Gutierrez, D.D., Newsam, C.J., Gronley, J.K., Mulroy, S.J., Perry, J.: A comparison of shoulder joint forces during ambulation with crutches versus a walker in persons with incomplete spinal cord injury. Arch. Phys. Med. Rehabil. **87**, 63–70 (2006)
3. Rudin, L.N., Levine, L.: Phys Ther Rev. **31**, 229–231 (1951)
4. Segura, A., Piazza, S.J.: Mechanics of ambulation with standard and spring-loaded crutches. Arch. Phys. Med. Rehabil. **88**, 1159–1163 (2007)
5. Goislard de Monsabert, B., Rossi, J., Berton, E., Vigouroux, L.: Quantification of hand and forearm muscle forces during a maximal power grip task. Med. Sci. Sports Exerc. **44**, 1906–1916 (2012)
6. Opila, K.A., Nicol, A.C., Paul, J.P.: Upper limb loadings of gait with crutches. J. Biomech. Eng. **109**, 285–290 (1987)
7. Opila, K.A., Nicol, A.C., Paul, J.P.: Forces and impulses during aided gait. Arch. Phys. Med. Rehabil. **68**, 715–722 (1987)
8. Parziale, J., Daniels, J.: The mechanical performance of ambulation using spring-loaded axillary crutches. Am. J. Phys. Med. Rehabil. **68**, 193–195 (1989)
9. Reisman, M., Burdett, R.G., Simon, S.R., Norkin, C.: Elbow moment and forces at the hands during swing-through axillary crutch gait. Phys. Ther. **65**, 601–605 (1985)
10. Sala, D.A., Leva, L.M., Kummer, F.J., Grant, A.D.: Crutch handle design: effect on palmar loads during ambulation. Arch. Phys. Med. Rehabil. **79**, 1473–1476 (1998)
11. Rossi, J., Berton, E., Grélot, L., Barla, C., Vigouroux, L.: Characterisation of forces exerted by the entire hand during the power grip: effect of the handle diameter. Ergonomics **55**, 682–692 (2012)
12. Medola, F.O., Paschoarelli, L.C., Silva, D.C., Elui, V.M.C. Fortulan, C.A.: Pressure on hands during manual wheelchair propulsion: a comparative study with two types of handrim, In: European Seating Simposium, pp. 63–65 (2011)
13. Tichauer, E.R., Gage, H.: Ergonomic principles basic to hand tool design. Am. Ind. Hyg. Assoc. J. **38**, 622–634 (1977)
14. Cobb, T.K., An, K.N., Cooney, W.P.: Externally applied forces to the palm increase carpal tunnel pressure. J Hand Surg. Am. **20**, 181–185 (1995)
15. Potter, B.E, Wallace, W.A.: Crutches. MJ. 3, 301, 1037–1039 (1990)
16. Rossi, J., Goislard De Monsabert, B., Berton, E., Vigouroux, L.: Handle shape affects the grip force distribution and the muscle loadings during power grip tasks. J. Appl. Biomech. **31**, 430–48 (2015)
17. Silva, D.C., Medola, F.O., Bonfim, G.H.C., Paschoarelli, L.C.: Using a pressure mapping system to evaluate contact pressure on hands during use of axillary crutches. Stud. Health Technol. Inform. **217**, 432–439 (2015)
18. Paschoarelli, L.C., Menezes, M.S.: Design e Ergonomia: aspectos tecnológicos. Cultura Acadêmica, São Paulo (2009)

19. Vink, P., Hallbeck, S.: Editorial: comfort and discomfort studies demonstrate the need for a new model. Appl. Ergon. **43**, 271–276 (2012)
20. Iida, I.: Ergonomia: Projeto e Produção. Edgard Blucher, São Paulo (2005)
21. Kuijt-Evers, L.F.M., Groenesteijn, L., Looze, M.P., Vink, P.: Identifying factors of comfort in using hand tools. Appl. Ergon. **35**, 453–458 (2004)
22. Boyles, J.L., Yearout, R.D., Rys, M.J.: Ergonomic scissors for hairdressing. Ind. Ergon. **32**, 199–207 (2003)
23. Groenesteijn, L., Eikhout, S.M., Vink, P.: One set of pliers for more tasks in installation work: the effects on (dis)comfort and productivity. App. Ergon. **35**, 485–492 (2004)
24. Silva, D.C., Inokuti. E.S., Paschoarelli, L.C.: Evaluation of discomfort in manual activities using hand mapping: the influence of age. Human Factors Des. **1**, 16–30 (2013)
25. Borrelli, J., Haslach Jr., H.W.: Experimental characterization of axillary/underarm interface pressure in swing-through crutch walking. J. Rehabil. Res. Dev. **50**, 423–436 (2013)

Design and Development of a Low-Cost Prosthesis Directed to the Activity with a Gasoline Brush Cutter: A Case Study

Daniel Ferrari, Gabriel Bonfim, Raphael Oliveira, Luis Paschoarelli and João Santos

Abstract In Brazil, the rate of people with disabilities resulting from amputation is relevant. The distribution of high-tech prostheses only meets a small portion of the population. On the other hand it is known that most of the industrialized products design in the world are developed to users considered "normal". This study proposed, through guidance to a group of technical students, the design and development of a low-cost prosthesis to an individual with disarticulation of the left wrist, seeking to provide opportunities for the subject to conduct a vegetation cutting activity with a gasoline brush cutter. Based on the knowledge assimilated during the technical course in mechanics, the group of students explored new possibilities of alternative materials and processes in the search for an affordable solution. The project resulted in a prosthesis that attends the anatomical, mechanical and functional needs required by the individual X product interface.

Keywords Inclusive design · Prosthesis · Low cost

D. Ferrari (✉) · G. Bonfim · L. Paschoarelli · J. Santos
UNESP - Univ. Estadual Paulista, Av. Eng. Luis Edmundo Carrijo Coube 14-01, 17033-360 Bauru, Brazil
e-mail: daniel.ferrari@etec.sp.gov.br

G. Bonfim
e-mail: gh_cb@hotmail.com

L. Paschoarelli
e-mail: paschoarelli@faa.unesp.br

J. Santos
e-mail: guarneti@feb.unesp.br

D. Ferrari · R. Oliveira
CEETEPS - Centro Estadual de Educação Tecnológica Paula Souza, Rua dos Andradas 140, 01208-000 São Paulo, Brazil
e-mail: rfantacini@gmail.com

M. Soares et al. (eds.), *Advances in Ergonomics Modeling, Usability & Special Populations*, Advances in Intelligent Systems and Computing 486,
DOI 10.1007/978-3-319-41685-4_40

1 Introduction

The human hand, a survival tool, is essential for the handling of food and objects. With its complexity and versatility, it has helped in the creation of innovations, assisting humans to develop themselves [1].

In Brazil, it is estimated that the incidence of amputations is 13.9 per 100,000 inhabitants/year. Globally, there is controversy regarding the number, ranging from 2.8 to 43.9 per 100,000 inhabitants/year, being more frequent in patients with vascular diseases. However, there are several etiologies related to amputation of limbs, such as neuropathic, trauma, tumors, infections and congenital [2].

Emerging technologies have worked in the development of modern prosthetic hands which are exceptionally functional and aesthetically attractive, but these resources have high costs. An advanced enough product, to meet the daily needs of an amputee, can reach costs that exceed US$ 30,000.00, but most people who live in developing countries cannot afford that [3].

On the other hand, most of the industrialized products in the world are not designed with the concepts of Universal Design, which does not allow a portion of the population, devoid of any part of the body, to use them fully.

Faced with this problem, it has been noted some efforts of the researchers who have been engaged in the search for cheap and simple solutions [4–8]. As regards the prosthesis applied to specific activities, some studies were found [9, 10].

The gasoline brush cutter with integrated combustion engine is an equipment used for cleaning and maintenance of urban and agricultural areas. It works by the engine power that transmits the movement to the blade through a rigid shaft. The machine is fastened on the right side of the user, through a harness, which controls the movements using two hand grips. Thus it is impossible for a person to use the product with just one hand (Fig. 1).

In this context, a group of students from a middle-level technical course in mechanics at CEETEPS (State Center for Technological Education "Paula Souza"), under the guidance of the authors, engaged in the design and development of a low-cost prosthesis to an individual with traumatic amputation of the hand up to the wrist level, so that he could fully operate a gasoline brush cutter.

2 Objectives

The objective of this study was to design and build a low-cost functional prosthesis for an individual with disarticulation of the left wrist, aiming to enable him to conduct, with effectiveness and comfort, all the tasks involved in working with a brush cutter. The research also sought, in the course of the experiment, provide students with the discovery of new materials and processes, and present them some concepts of comfort and ergonomics.

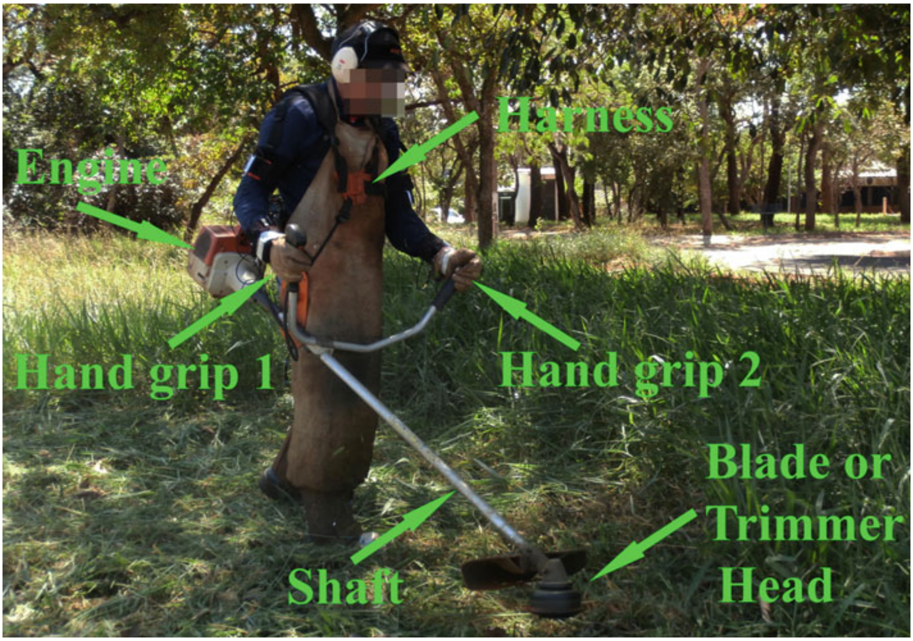


Fig. 1 Brush cutter operator

3 Case Study: Choice of Subject, Design, Construction and Validation of the Prosthesis

3.1 Figures

The person invited to perform the tasks was male, in the date of the experiment he was 33 years old and weighed 51 kilos. He had full physical and mental health, but at 12 years old, lost his left hand in an accident. Since then he never used any type of prosthesis, thus having some limitations in certain activities that require the use of both hands. The subject was informed of occasional risks that could suffer during the research and agreed to fully participate in the experiment.

3.2 Design

For the beginning of prosthesis design it was necessary to collect some measures of the individual's right arm. The elbow-wrist and elbow—closed hand dimensions were taken with an anthropometer and they were essential, because with this information it was possible to equalize the reach of the hand grips of both members and respecting the maximum limits of the prosthesis.

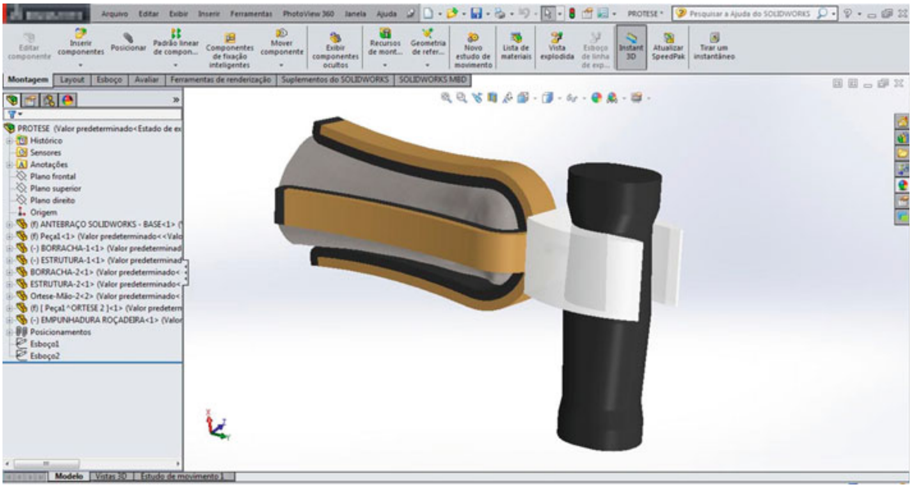


Fig. 2 Project in a 3D design software taking into account the diameter of the hand grip

It was also used 3D scanning technology in the collection of dimensions, thereby obtaining a three-dimensional digital model of the amputated region. This step was important because, with the geometry available in the computer, it was possible to explore alternatives in the 3D design software (Fig. 2).

For the development of the functional prosthesis project, the group focused on the research of materials that were alternative and little explored by professionals in the orthopedic area, taking into account the combination of comfort and mechanical resistance.

It was found in water pipes made of PVC (Polyvinyl Chloride) a possible solution to the fit of the amputee area. Two strips arranged as a kind of exoskeleton wrapped in the forearm could be fixed effectively.

In order to avoid the discomfort caused by direct skin contact with the PVC strips, the team sought to solve this problem with the addition of foam rubber strips, material used in abundance for sealing, damping and finishing of various domestic and industrial situations. It was chosen the material with relatively comfortable density and hardness (density from 0.40 to 0.90 g/cm^3 and hardness between 10 and 90 Shore A) in order not to cause injury to areas of skin contact.

Finally, the gripper, made of nylon and produced from the polyamide, was de-signed starting from the hand grip diameter of the brush cutter, establishing a slight pressure fitting between the two parts.

3.3 Construction

The study continued to obtain a model of the amputated area with real dimensions. To perform this task it was developed a molding container also made of PVC pipe.

It was used material for dental molding to reproduce the negative part. This type of material faithfully reproduces the entire area of the anatomy to be reproduced, but it solidifies in a few minutes. Therefore the help of a dentist was required.

The amputated area was slowly inserted into the pipe and, after solidification of the molding material, the arm was carefully removed, thereby obtaining the negative part. Then the negative mold was filled with common plaster, and within a few minutes, it was obtained the positive part of the model, which showed very close to the real member dimensions (Fig. 3).

It was initiated the construction of the prosthesis pulling out two strips of a PVC tube with 50 mm diameter. This task was carried out using a handsaw and then the pieces were sanded.

Thereupon, the parts were heated in boiling water, shaped and pressed with the aid of a carriage clamp. This step took about thirty minutes.

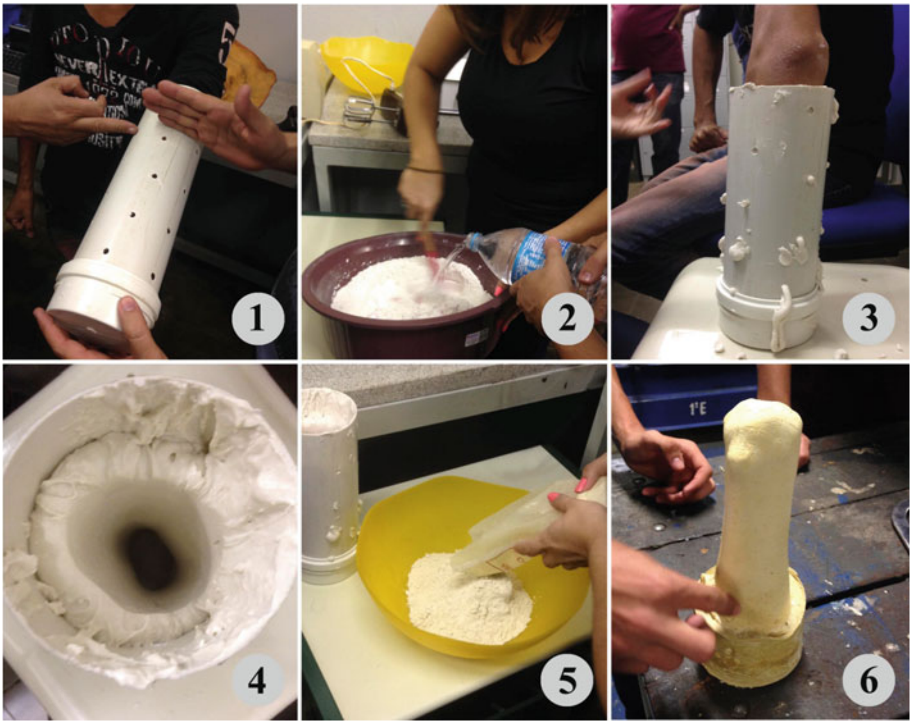


Fig. 3 Extraction process of negative and positive molds

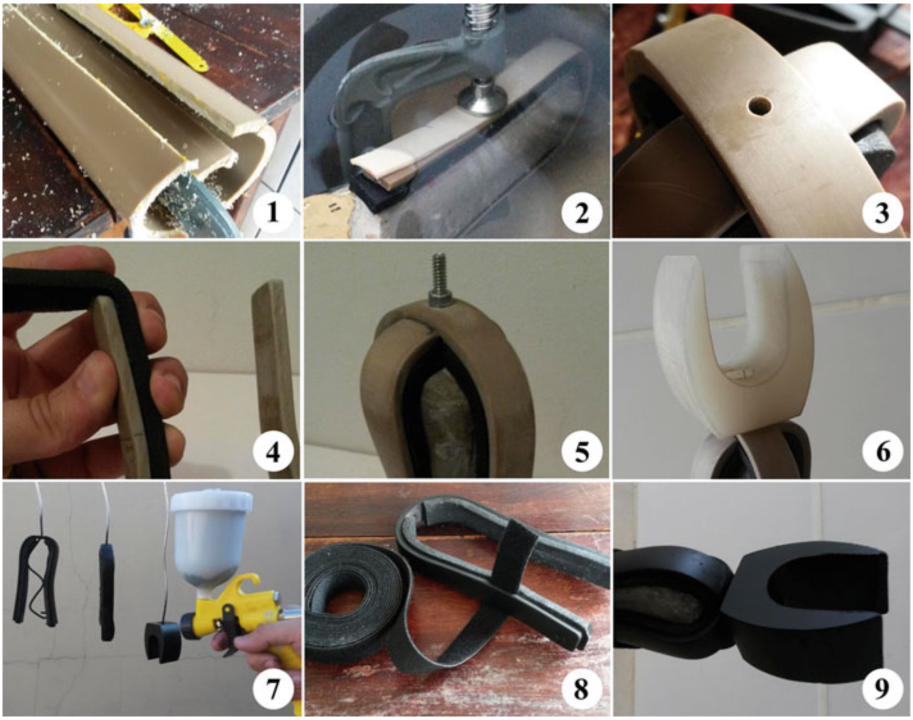


Fig. 4 Steps for constructing the prosthesis

A hole was made at the end of the stump region and then the parts were joined together with a carriage bolt. There was a concern that the bolt head could result in injury, and so it was embedded in a cavity made inside the strip.

The foam rubber strips were fixed with contact adhesive, and there was a concern about the rounding of the edges in order not to cause injury in the contact regions.

The gripper was manufactured with waterjet technology, and it received a hole in its internal region where the end of the bolt was embedded.

The piece received a synthetic enamel paint cover in black, and finally the contact closures were sewn (Fig. 4).

3.4 Validation

Test in a Universal Testing Machine. The group became aware of the importance of carrying out a simple simulation of mechanical strength, because a possible breaking of the piece in use could seriously injure the user. Thus it was made an identical model of the prosthesis, which was attached to a piece of metal with

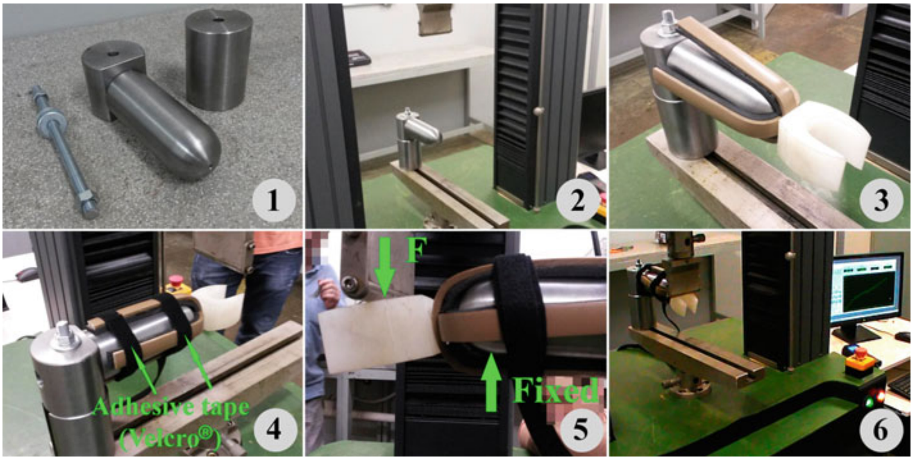


Fig. 5 Simulation in a universal testing machine

similar dimensions to the amputated area. The piece was fixed in a universal testing machine and received gradual and constant force. The model began to suffer slight deformation at 450 N, but it did not break (Fig. 5).

Test in the gym. Before the final, test the subject was asked to perform a test of the prosthesis in a gym in order to find out what are the limits of strength of his upper limbs. With the help of a professional, the subject was submitted to exercises in various equipments and in none of them he was able to exceed a force greater than 450 N (Fig. 6).

Working with the brush cutter. The final test consisted of inviting the subject to try to perform all the tasks required for the use of a gasoline brush cutter.

It is important to highlight that the subject had never operated this type of equipment and before the execution of this test he received all the necessary guidance to perform the activity safely.

Without the prosthesis, the user fueled the equipment with gasoline, then he put on his apron, leggings, harness, glove, glasses and the hearing protection. Only then he put on the prosthesis and performed the ignition procedures of the machine, the

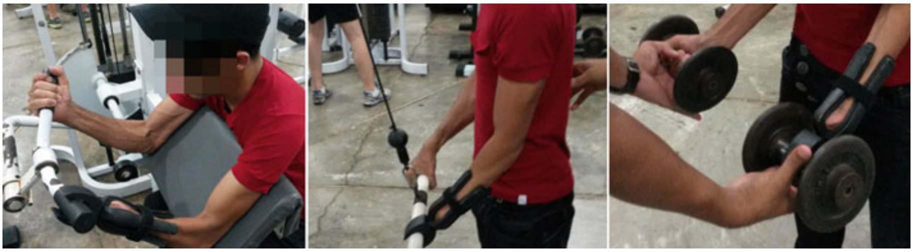


Fig. 6 Individual testing the prosthesis in a bodybuilding gym

Fig. 7 User performing the necessary tasks to work with the gasoline brush cutter

attachment of the harness to the equipment and the attachment of the gripper to the hand grip of the machine.

The subject easily performed the execution of vegetation cutting.

In operation with this equipment, eventual situations where the operator needs to detach quickly from the brush cutter occur frequently, therefore the individual was asked to perform some times the movements of engaging and disengaging the gripper to the hand grip of the machine, so that the team could certify the security offered by the prosthesis. The individual was also able to perform the procedure with ease.

The subject used the equipment for about thirty minutes and, after the use, he did not utter any complaints about discomfort in the fitting region of the amputated area (Fig. 7).

Costs. The value per hour of the professionals who participated in the development of the prosthesis have not been calculated because everyone worked for free, and the use of school facilities and the gym did not generate cost to the research team. Therefore it was calculated only the cost of materials used in the construction of the prosthesis (Table 1).

Table 1 List of materials used in the construction of the prosthesis and their costs

Item	Quantity	Cost
PVC pipe Ø100 mm	30 cm	US$ 0.65
PVC pipe cap Ø100 mm	01 unit	US$ 1.05
Material for dental molding	02 kg	US$ 6.45
Plaster	01 kg	US$ 0.69
PVC pipe for cold water Ø50 mm	40 cm	US$ 0.74
Nylon bar Ø80 mm	05 cm	US$ 2.40
Carriage bolt with nut Ø3/16″ X 1.1/4″	01 unit	US$ 0.03
Foam rubber strip 20X5 mm	40 cm	US$ 0.42
Contact adhesive	01 tube of 30 g	US$ 1.12
Contact closure	50 cm	US$ 0.09
Synthetic enamel paint	01 can of 225 ml	US$ 3.25
	Total	US$ 16.89

4 Conclusions

At the end of the experiment it is concluded that the proposed objectives were achieved because the prosthesis fully met the anatomical, mechanical and functional needs required by the user x product interface.

The subject being studied was able to perform all the tasks required in working with the equipment, with no complaints about discomfort after the test in the field.

The research team was able to develop a comfortable and functional prosthesis through the use of simple manufacturing techniques and the use of alternative materials, with production costs below those found in conventional prostheses, making the product affordable to other individuals with the same problem.

Students could learn new techniques and new materials, as well as brief concepts of ergonomics and anthropometry, issues that were distant from the topics of disciplines offered by the course.

Acknowledgments The authors gratefully acknowledge CEETEPS (Centro Estadual de Educação Tecnológica “Paula Souza”); UNESP—Universidade Estadual Paulista; the students: Abner da Silva, Edcarlos Julião, Felipe Pereira, Vinícius Teixeira e Wallace Gimenes; the dentist Dr. Talita Caira Silva; and all the professors of the Technical Course in mechanics of the State Technical School “Antônio de Pádua Cardoso”.

References

1. Kapandji, A.I.: Fisiologia Articular (Membro Superior). Guanabara Koogan, Rio de Janeiro (2000)
2. Montiel, A.: Caracterização de pessoas submetidas à amputação. Enf. em Foco. **3**, 169–173 (2012)

3. Lightbody, S.: Design of an articulated thumb for a low-cost prosthetic hand. In: 12th Marcus Conference, pp. 1–12. Sweet Briar College, Sweet Briar (2010)
4. Dobner, D.: A simple cosmetic partial-hand prosthesis. J. Hand Ther. **1**, 209–212 (1988)
5. Campbell, G.S., Gow, D., Hooper, G.: Low cost cosmetic hand prostheses. J. Hand Surg. **17B**, 201–203 (1992)
6. Strait, E.: Prosthetics in developing countries. Prosthetic Resident (2006)
7. Abraham, Z., Kwon, D.B., Solomon, T., Xie, M., Yeh, K.: Control of an affordable hand and wrist prosthesis. In: 15th Research Symposium, Rutgers School of Engineering, pp. 1–13. Rutgers School, Rutgers (2015)
8. Sundfeld, L., Nogueira, J.L.C., Arêdes, S. V., Júnior, L.S., Barbosa, L.F.W.: Estudo e Desenvolvimento de uma Prótese de Mão Humana Robótica de Baixo Custo para Crianças. In: 6th Encontro Latino Americano de Pós-Graduação – Universidade do Vale do Paraíba, pp. 1–4. Univap, São José dos Campos (2015)
9. Weir, R. F.: Design of artificial arms and hands for prosthetic applications. In: Kutz, M. (ed.) Standard Handbook of Biomedical Engineering & Design, pp. 32.1–32.61. Mcgraw-Hill, New York (2003)
10. Gouldstone, A.: Prosthetic Adapter for Agricultural Machinery. Northeastern University, Boston (2014)

Aspects of the National Catalogue of Assistive Technology Products of the Ministry of Science, Technology and Innovation in Brazil: A Survey on the Degree of Knowledge of the Catalog

Roberta Lucas Scatolim, João Eduardo Guarnetti dos Santos, Paula da Cruz Landim, Silvia Cristina Mazaro Fermino and Denise Cardozo

Abstract This article is a case study on the National Catalogue of Assistive Technology developed by the Ministry of Science, Technology and Innovation, along with the Institute of Social Technology (ITS Brazil). The available services provided by the catalog are covered by the assistive technologies, citing some references about such technologies. A survey was conducted with thirteen people with physical, visual or auditory, who answered a form with seven questions in order to know if these users know the book or have purchased a product via the platform.

Keywords National Catalog of Assistive Technology · Accessibility · Assistive Technology · Disabilities

1 Introduction

The National Catalogue of Assistive Technology Products (TA) is part of an initiative of the Ministry of Science, Technology and Innovation, through the Department of Science and Technology for Social Inclusion (MCT/SECIS), designed and conducted in partnership with the Institute Social Technology (ITS BRAZIL).

R.L. Scatolim (✉) · J.E.G. dos Santos · P. da Cruz Landim
UNESP–Univ. Estadual Paulista, Av. Eng. Luiz Edmundo C. Coube 14-01,
Bauru 17033-360, Brazil
e-mail: robertascatolim@gmail.com

S.C.M. Fermino
USP – Universidade de São Paulo, Av. Bandeirantes 3900, Monte Alegre,
Ribeirão Preto 14040-906, Brazil

D. Cardozo
FACULDADE SÃO LUÍZ, Rua Floriano Peixoto 839-873,
Centro, Jaboticabal 14870-370, Brazil

M. Soares et al. (eds.), *Advances in Ergonomics Modeling, Usability & Special Populations*, Advances in Intelligent Systems and Computing 486,
DOI 10.1007/978-3-319-41685-4_41

The catalog is a service that allows people with you-rem special needs access to assistive technology product information, the MCTI/SECIS in accordance with the National Plan of Rights of Persons with Disabilities Live without limit [1].

The Catalog is an online tool that allows the user to search by Assistive Technology products manufactured and/ or distributed in Brazil, according to the categories of ISO 9999-2007 in order to bring information, expand the usabiliness and bring more quality of life of the disabled and elderly. Johnson [6] states that the use of robotic rehabilitation machines, associated with physiotherapy, provide patient rehabilitation in a shorter time compared to patients who do not use such procedures.

The ISO 9999-2007 ranks supporting products developed for people with disabilities. Currently, National Catalog Assistive Technology Products has cataloged products that meet hearing impairment, intellectual impairment, visual impairment, physical disability, multiple deficiency and elderly [5]. The registered products are:

- Support products for the medical treatment (198)
- Support products for skills training (78)
- Orthotics and prosthetics (240)
- Support products for personal care and protection (170)
- Support products for personal mobility (138)
- Support products for household activities (25)
- Furniture and adaptations for housing and other buildings (91)
- Support products for communication and information (362)
- Support products for handling objects and devices (31)
- Support products for environmental improvement, machinery and tools (26)
- Support products recreational activities (113)

According to the Technical Assistance Committee, Assistive Technology is "products, resources, methodologies, strategies, practices and services that aim to promote functionality, related to the activity and participation of people with disabilities, disability or reduced mobility, aiming at their autonomy, independence, quality of life and social inclusion "(the Technical Assistance Committee—ATA VII)" [2].

To prepare the catalog, the ITS Brazil team conducted research to better understand the Brazilian market, participated in events and fairs, in order to know with work and what kinds of assistive technology, its researchers and companies. Visited the State Reference Center of Personal Autonomy y Ayudas Techniques (CEAPAT) in Madrid (Spain), precursor in developing a Technical Assistance Catalog.

Cook and Hussey [3] explain the concept of assistive technology through the engineering rehabilitation, or engineering processes and services, stating that according to psychosocial aspects, which individual is an individual with rights to active social interaction, regardless of their ability, that is, to be the bearer of a disability or restriction in daily life.

The catalog has free access both for inspection and for the registration of products, and is available on the Portal of Assistive Technology at http://www.assistiva.org.br/ address and since 2008, the National Catalogue of Products

Technology Assistive joined the International Alliance of Information providers in Assistive Technology—www.ati-alliance.net, which covers eleven countries: United States, Italy, Germany, Belgium, England, Denmark, Australia, Ireland, Brazil, Spain and France [1].

The World Health Organization (WHO) estimates that worldwide there are over 1 billion people with disabilities. In Brazil, according to the 2010 Census, 45.6 million people have some form of disability, conducted by Brazilian Institute of Geography and Statistics (IBGE) [4].

In the main catalog page, as shown in Fig. 1, there is a search engine and the following information: the deficiencies which are registered Products: hearing

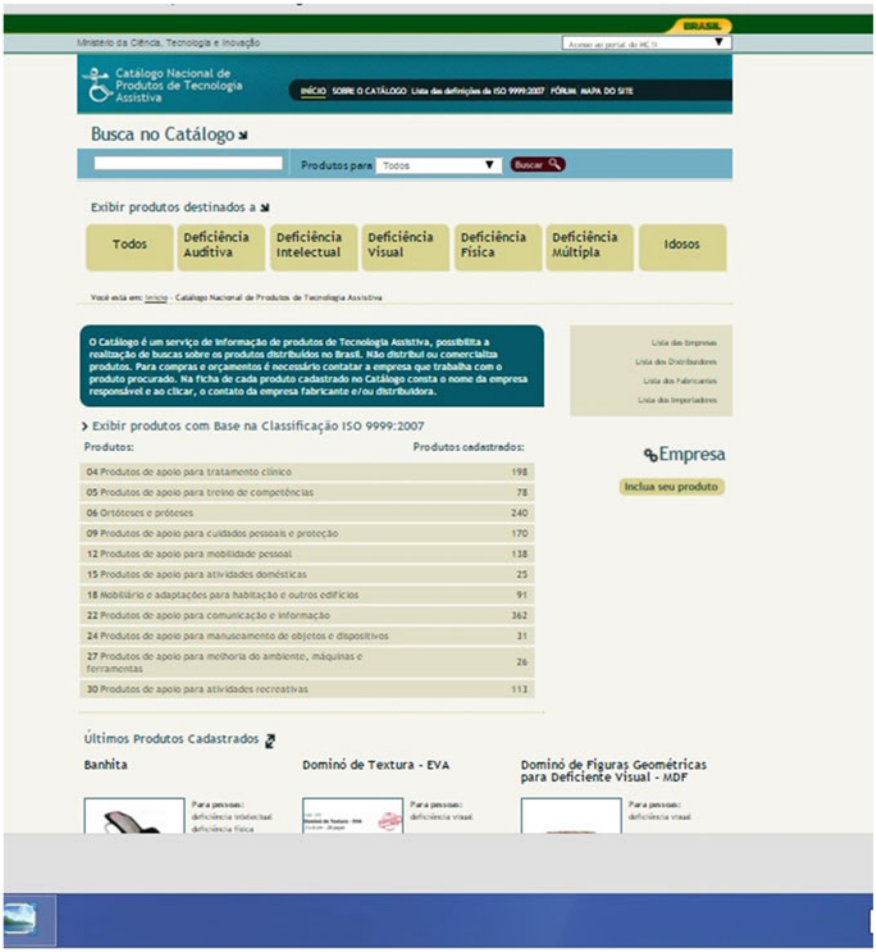


Fig. 1 Home of the catalog national assistive technology products. *Source* Ministry of Science, Technology and Innovation of Brazil

impairment, intellectual, visual, physical, multiple, and products for the elderly. The lists of companies, distributors, manufacturers and importers. The last registered products and products based on ISO 9999: 2007, which provides assistive products for persons with disabilities, classification and terminology of such products even include software, and are classified according to function.

This study aimed to investigate whether carrier user deficiencies know or have already purchased a product through the National Assistive Technology Products Catalog. This knowledge can help designers and manufacturers in the design of effective information to show the catalog facilities, promoting the safe and comfortable buying.

Despite the significant number of Assistive Technologies, so important to reduce physical and social barriers, we will see in applied research for this study, the majority of people with disabilities who responded to the form, are unaware about the National Catalogue of Assistive Technology Products, a facilitator in the search and acquisition for such products.

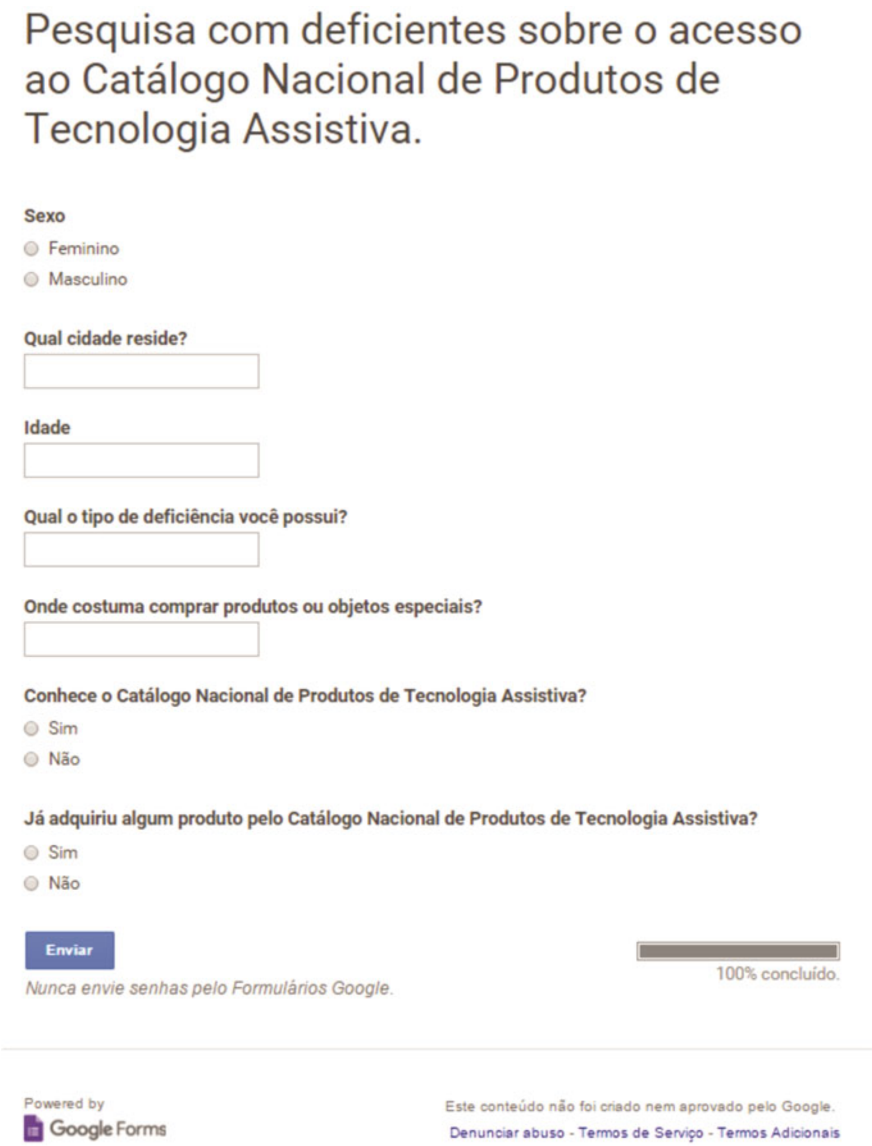
In this context, also cite the importance of Design adapted resources and services for people with permanent or temporary disabilities are essential to ensure effective accessibility in various environments of society, ranging from mobility without restriction to the acquisition and use of a single product or service.

2 Materials and Methods

This study was used as a complement to a thesis being developed-Doctoral Program of FAAC—School of Architecture, Arts and Communication—AAC/UNESP—Univ. Estadual Paulista, Bauru, SP. Data were collected through Google Forms, which were referred to special needs known by researchers. This strategy avoids errors of variables and defines that only individual with limited capacity to respond. Thirteen volunteers participated in this study. The formulate river contained six questions, as shown in Fig. 2, whose main objective was to find out whether users with disabilities know the National Catalogue of Assistive Technology products.

Data were collected through a form available on the Google platform, sent to a predetermined public, to ensure that it was really a man with a disability who was responding to the survey. Thirteen volunteers participated in this study. The form contained seven questions, as shown in Fig. 2, and the main objective of the research was to find out whether users with disabilities know the National Catalogue of Assistive Technology products.

The issues addressed in the report were: Sex? City of residence? Age? What kind of disability you have? Usually where to buy special products (assistive technology)? Know the National Catalogue of Assistive Technology Products? Already purchased a product through catalog?



Pesquisa com deficientes sobre o acesso ao Catálogo Nacional de Produtos de Tecnologia Assistiva.

Sexo

- Feminino
- Masculino

Qual cidade reside?

Idade

Qual o tipo de deficiência você possui?

Onde costuma comprar produtos ou objetos especiais?

Conhece o Catálogo Nacional de Produtos de Tecnologia Assistiva?

- Sim
- Não

Já adquiriu algum produto pelo Catálogo Nacional de Produtos de Tecnologia Assistiva?

- Sim
- Não

Enviar

100% concluído.

Nunca envie senhas pelo Formulários Google.

Powered by Google Forms

Este conteúdo não foi criado nem aprovado pelo Google.

Denunciar abuso - Termos de Serviço - Termos Adicionais

Fig. 2 Search form applied

3 Results

The sample of thirteen individuals was divided in three women and ten men, representing 22 % of women and 78 % men, mean age 45. All subjects who answered the form live in Brazil, in the cities of Jaboticabal, SP (77 %); Belo

Horizonte, MG (7 %); Florianópolis, SC (8 %); and Araraquara, Brazil (8 %). Individuals residing in Brazil, in the cities of Jaboticabal and Araraquara (SP); Belo Horizonte (MG); Florianópolis (SC). When asked what type of disability has, the subjects responded; Physical (54 %); Upper limb reduction (8 %); Motor (15 %); Visual (15 %); Hearing (8 %).

The question of how the subject is to acquire special products, we obtained the following answers: orthopedic shops (38 %); Do not know (8 %); Local sites (8 %); Internet (15 %); Physical and shopping sites (8 %); Do not buy (8 %); Games (8 %); Stores indicated by physicians (8 %).

Of all participating subjects, 92 % (ninety-two percent) do not know that there is the National Catalogue of Assistive Technology Products, and consequently never researched or purchased a product via the platform (Fig, 3).

When asked about how to purchase special products, re-ponder individuals: Orthopedic shops; Do not know; Local shops; Internet; Physical stores and sites; I do not buy; games; Stores Indicated by my doctor (Fig. 4).

In total, 92 % (ninety-two percent) do not know that there is catalog of assistive technology products, and consequently never purchased a product for the platform (Fig. 5).

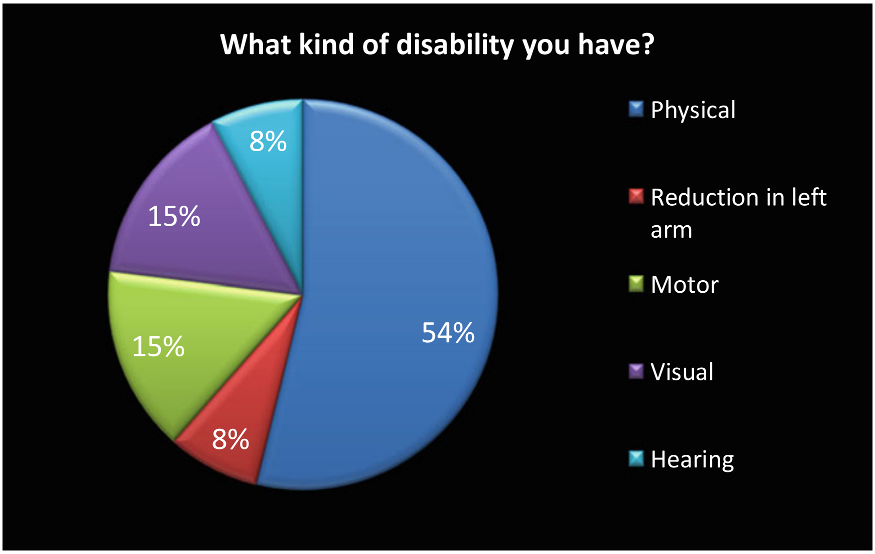


Fig. 3 Types of disabilities of the users of the research

Fig. 4 Where users buy special products

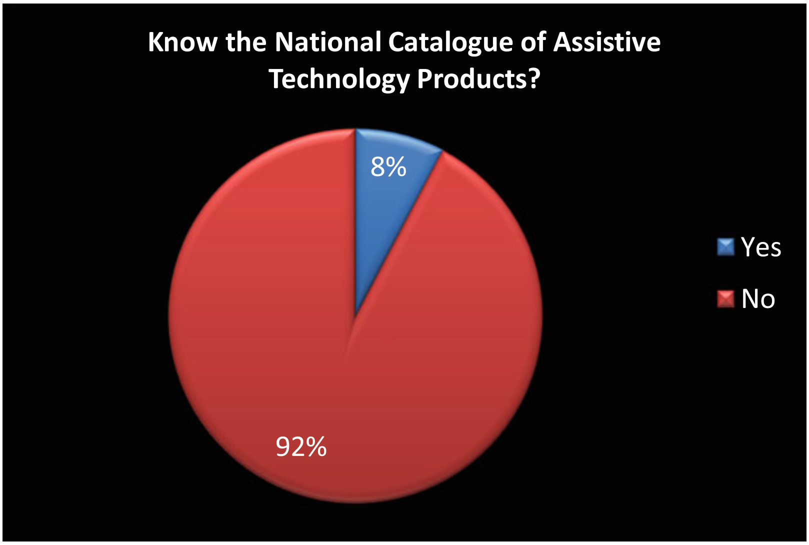


Fig. 5 Question about the degree of knowledge of the National Assistive Technology Products Catalog

4 Discussion

This article investigated whether some carriers Brazilian deficiencies know that there is National Catalogue of Assistive Technology Products developed by the Ministry of Science, Technology and Innovation, through the Department of Science and Technology for Social Inclusion (MCT/SECIS), along with Institute of Social Technology (ITS BRAZIL).

Despite the convenience the catalog brings to individuals with disabilities, few know this means of information, as it has access to internet and other media.

The main conclusion of this study is that makes up most necessary information about the catalog, which also brings ease to the user's life to purchase special products, is a way to approach companies, products and served directed will assistive technology.

5 Conclusion

This study aimed to investigate some individuals with disabilities in order to know if they know and/or have already purchased a product through the National Assistive Technology Products Catalog, developed by the Ministry of Science, Technology and Innovation, through the Department of Science and Technology for Social Inclusion (MCT/SECIS), by the Institute of Social Sciences Technology (ITS BRAZIL).

Despite the convenience that the catalog can bring brings to people with disabilities, most of those who responded to the survey, 92 % do not know the platform, even though access to the Internet and other media, necessary criterion for filling out the form.

The National Catalogue of Assistive Technology Products is one of the main means of access to purchase information products and services for the disabled, elderly or with reduced capabilities. Through the catalog, the user is assured of acquiring special or assistive products safely, amid the significant irregularities trade online. Furthermore, all product categories are in accordance with ISO 9999: 2007, which ensures the safety of the assistive technologies available.

Even with the significant number of people with disabilities in Brazil, 45.6 million, many do not have access to suitable products, for lack of financial resources and lack of access to information and companies developing such products. Thus, we realize after this research that there is need for more information on the National Catalogue of Assistive Technology products, thus approaching companies, assistive technologies and persons with disabilities.

References

1. BRAZIL. Ministry of Science, Technology and Innovation.: National catalog of Produ-tos Assistive Technology. Available in http://assistiva.mct.gov.br/ Acessed 03 Dec 2014
2. BRAZIL. Justice Ministry.: CORDE—on Technical Assistance Committee. Available in http://www.mj.gov.b. Acessed 01 Dec 2014
3. Cook, A.M., Hussey, S.M.: Assistive Technologies: Principles and Practice, 2nd edn. Mosby, St. Louis (2002)
4. IBGE. Brazilian Institute of Geography and Statistics.: Census 2010. Ca-general characteristics of the population, region and people with disabilities. Available in ftp://ftp.ibge.gov.br/Censos/Censo_Demografico_2010/Caracteristicas_Gerais_Religiao_Deficiencia/caracteristicas_religiao_deficiencia.pdf Accessed 11 Sep 2013
5. ISO 9999.: Assistive products for persons with disability: classification and terminology. (2007). Available in http://www.ifap.ru/ictdis/iso001.pdf. Acessed 12 July 2015
6. Johnson, M.J.: Recent trends in robot-assisted therapy envionments to improve real-life functional performance after stroke. J. NeuroEngineering Rehabil. **3**, 3–29 (2006)

Development of a Device for the Aid in Locomotion Child with Physical Disabilities

Márcio Catapan, Raquel Venancio and Maria Lucia Okimoto

Abstract The inclusion of children with physical disabilities is difficult by the prejudice of society and the inability to move around on their own. For these locomotion is possible, it is necessary to use devices that assist in their autonomy. An alternative Assistive Technology that provides the march to the handicapped child is a walker. The walkers models found on the market are designed to meet most of the physical, generalizing them; This makes in some cases, unsuitable or little effect. The purpose of this study consists of a mechanical walker project to assist in the motor development of the lower limbs of a child with cerebral palsy diplegia type, providing her well-being and security. For this, the most important functions of some existing models on the market and related to key customer needs were surveyed through a case study. From this information and improvements identified during the development of this study, it was developed and tested functional device prototype that met the expected purpose, validated by a special child with the problem described.

Keywords Product development · Assistive technology · Physical disability · Diplegia

M. Catapan (✉) · R. Venancio · M.L. Okimoto
Department of Graphic Expression, Federal University of Parana (UFPR), Curitiba, Brazil
e-mail: marciocatapan@ufpr.br

R. Venancio
e-mail: raquel.venancio@gmail.com

M.L. Okimoto
e-mail: lucia.demec@ufpr.br

M. Soares et al. (eds.), *Advances in Ergonomics Modeling, Usability & Special Populations*, Advances in Intelligent Systems and Computing 486,
DOI 10.1007/978-3-319-41685-4_42

1 Introduction

For Peace [1], "disability is any and every commitment that affects the integrity of the person, causing damage in their locomotion, coordination of movements, speech, understanding of information, in spatial orientation or perception and contact with others. That is, any loss or abnormality of structure or psychological function, physiological or anatomical, which manages incapacity for activity performance within the considered normal for a human being."

In Brazil, according to IBGE [2], 45.6 million people reported having at least one type of disability, which corresponds to 23.9 % of the population. Visual impairment was more pointed, reaches 18.8 % of the population, i.e., 35.7 million Brazilians, followed by motor disabilities with 7 %, with 5.1 % hearing and mental with 1.4 % (Fig. 1).

The IBGE [2] also shows the significant differences between people with Defici-perience and the general population, 61.1 % of the population aged 15 and over with disabilities have no education or have only completed elementary, a percentage that drops to 38.2 % for people without disabilities (Fig. 2). Of the 44 million disabled people who are of working age, 53.8 % are unemployed or outside the labor market.

Given these data, it is clear the difficulty faced by disabled people in our society. They are liable to be discriminated against in the communities where they live or excluded from the labor market. Since the dawn of societies, the process of social exclusion unfitted people with special needs, marginalizing and depriving them of liberty.

In recent years, national and international movements have sought the development of integration and inclusive education policies such as the Convention on

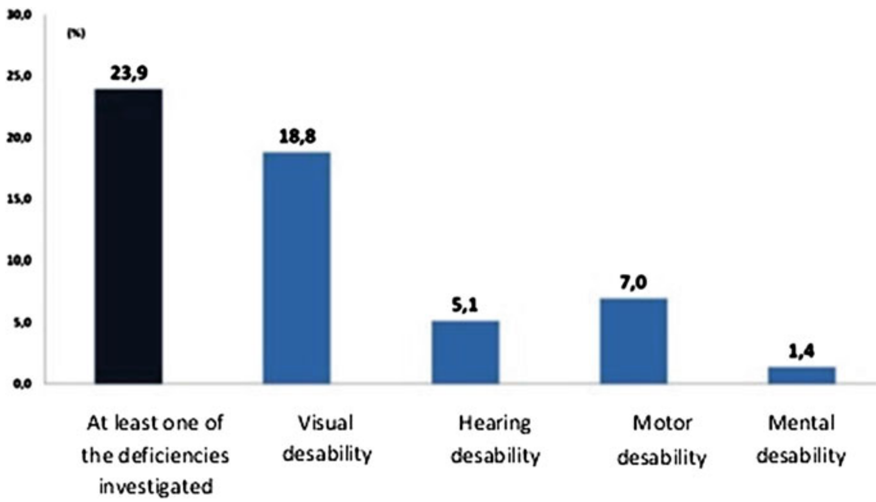


Fig. 1 Percentage of the population with disabilities and the most common types found

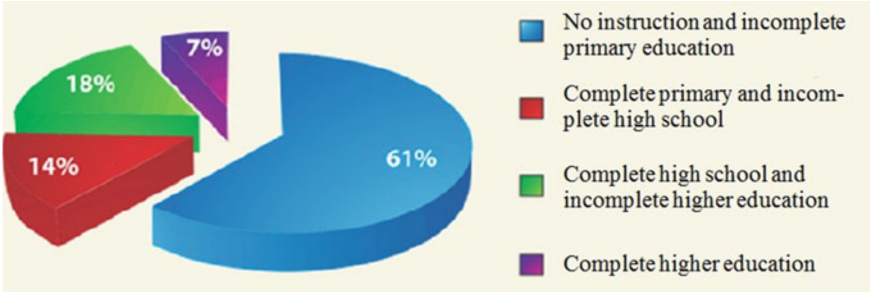


Fig. 2 Education percentage of people with disabilities in Brazil

the Rights of Persons with Disabilities adopted by the UN Assembly on March 30, 2007 and ratified by Brazil through Decree No. 6949/2009, as an amendment to the Federal Constitution, which emphasizes the relationship of the person with disabilities with the social environment where they live and their barriers, the situation of dependence that this relationship causes and the social participation. She also tells us that "today is not the individual threshold for disability, but the barriers in the spaces in the physical environment, transportation, information, communication and services."

Mayston [3] states that the deficiencies presented by a child with cerebral palsy influence the activity and social participation of the same. The social integration of children with disabilities or not, is of utmost importance to their physical and mental development, because through it stimuli are created, positively focusing on growth.

The inclusion of children with motor disabilities is hampered both by prejudice of society, such as the inability to move around on their own. This reduction in mobility obstructs also the regeneration since, according to Pereira [4], the practice of physical activity, even if to a lesser degree, contributes to the rehabilitation of any kind of disability.

For the locomotion of these children is possible, it is necessary the use of devices that assist in their autonomy. These devices are called Assistive Technology (AT) and allow the child locomotion, interaction with others and participation in appropriate activities to its development, as exemplified by Cowan [5] and Wintergold [6].

A TA alternative that provides ambulation (walking) to the disabled child is a walker. However, the models found in the market are designed to meet most of the physical, generalizing them. This makes in some cases, unsuitable or little effect.

The challenge of this study is to create more possibility to include the person defi-science in society, with the key point the user's walking ability. As are many types of disabilities, this project develops a walker for a child with diplegia, that is, when the bearer of cerebral palsy develops motor frame dysfunctions of the lower limbs, struggling to stay standing or when presenting involuntary movements and tortuous during the act of walking.

This research aims to design a device capable of collaborating with the motor development of lower limbs of children with diplegia, ensuring autonomous mobility of this child.

For the realization of the project have been defined following the following steps:

- Make a case study for the child's specific situation Lucas Senna, by-tient with cerebral palsy diplegia type, and develop a unique product for it;
- Identify the main difficulties that you find in your own walk-pain;
- Identifying the main problems and possible improvements in the models available in the market;
- Develop solutions to suit the product improving the quality and effectiveness of the equipment;
- Build a prototype and validate their results by conducting practical tests with the child who needs the device, being supervised by a professional physical therapy area.

2 Research Methodology

The methodology applied for the development of the project for the study of the case in question was the Rozenfeld et al. [7], through which it comes to the design and prototyping of a product that meets both customer needs as the design requirements. This approach corresponds to bibliographic research, benchmarking, market analysis, cost analysis and survey of customer needs.

2.1 Case Study

By analyzing the difficulties that a child with diplegia have to walk and to progress faster in physical therapy, proposed the development of a specific walker for this patient, with the main purpose of meeting the needs of this child and also the people who watch to her. For this, there was a study of the most important functions of some existing walker models on the market, making necessary improvements and adding them to a single project to address the lack of quality, simplicity in handling and price com-petitive in the Brazilian market.

Although the product is for a boy, the potential customer is the responsible adult for the special user child's walker and therefore also responsible for the purchase of equipment.

For the collection of customer needs information, it was developed and applied a questionnaire that contained nine discursive character of questions that have been applied by the interviewers and answered by women (mother and physiotherapist responsible for the child) verbally and in written form.

3 Development and Results

There is little variety of walkers, especially in Brazil, with the function to assist in the practice of walking and standing posture in children with cerebral palsy or syndromes affecting the locomotor system.

They are characterized by their complex assembly and operation, they are usually purely mechanical mechanisms and high value.

3.1 Benchmarking

In order to compare the products already on the market in order to obtain a competitive advantage, we used the benchmarking (Table 1), between three different products, and the Brazilian brands Vanzetti [8] and Expansion [9], and foreign R82 [10], both with the function of collaborating with the motor activity of the lower limbs of children with diplegia.

The state walker used by the patient does not comply with the essential functions which was determined, these being the practice of walking and standing position. In addition to these problems have been identified other flaws in the project as lack of comfort, high weight, size, excess settings.

Table 1 Comparison of three walker models

<table>
<tr><th>Walker of Vanzetti Europa model</th><th>Walker expansion of transfer model</th></tr>
<tr><td></td><td>
</td></tr>
<tr><td colspan="2">Walker of R82 Mustang model</td></tr>
<tr><td colspan="2"></td></tr>
</table>

3.2 Product Definition

Relating the customer's needs with the requirements of the project through the House of Quality tool (Fig. 3), also known as Quality Function Deployment (QFD), they were listed in degree of importance the following criteria must be met for the product.

1. Change in central structure for maintaining stability user standing in the standing posture (standing) and practice running properly;
2. Ensure not the walker tip over and the child fall.
3. Improved device steering control (handling);
4. Ease of locomotion without overexertion;
5. Reducing the weight of the equipment;
6. To reduce and simplify the amount of adjustments.

3.3 Design and Product Prototype

With the application of the methodology [7], corresponding steps Initial Planning Informational Design, Conceptual Design and Detailed Design, has come up with a design. At first it was built 3D initial prototype, made in a CAD software and

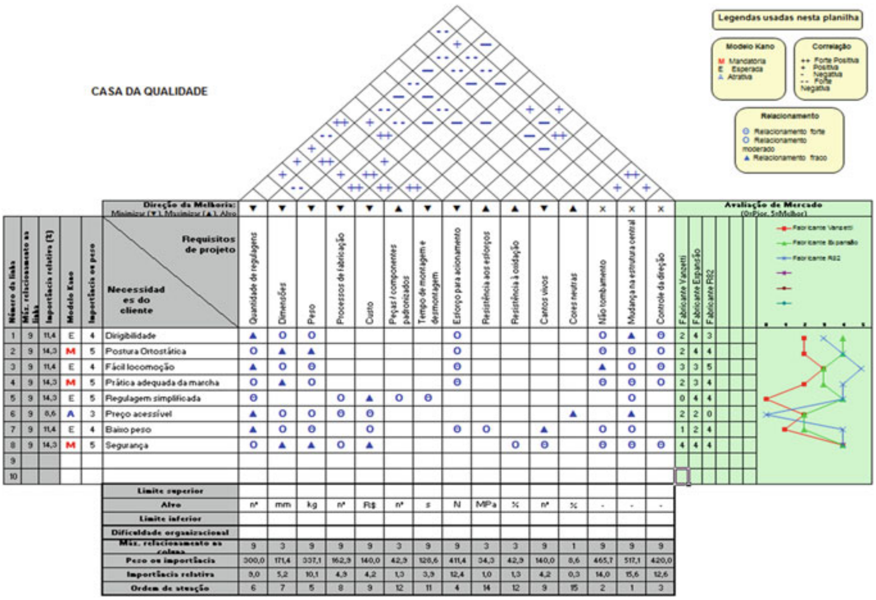


Fig. 3 Quality House model used to relate the needs of customers with the design requirements

simulated in a CAE, whose main objective was to serve for preliminary tests. Further improvements have been made and made a functional final version, with main structure in SAE 1020 steel (Fig. 4).

We have found some difficulty in the design of software, because the center of mass analysis and product stability. However, the physical construction has been completed in accordance with the designed.

The development of the prototype allowed the verification of the most important points for the success of the final product. Are they:

- Attention to customer requirements and design;
- Performance and functionality of the product;
- Visual aesthetics of the product.

The construction of the prototype can be divided into: study of materials, the prototype installation and implementation of product functionality tests. The selection of materials that were used in the construction of the device for locomotion aid, was validated following some important criteria, such as cost, structural strength, ergonomics and easy availability in the market. For mounting, the most important processes used at this stage were folding, cutting, drilling and welding. The sanding procedures, painting and installation accessories are also included in this step.

Fig. 4 3D modeling of the new product

3.4 Test for the Prototype Validation

The validation of the prototype had the supervision of a physical therapy professional. It can be considered the stage where the whole process of planning and manufacturing of equipment is tested by the user, in order to analyze the successes and possible errors generated during the project.

The prototype walker for children with disabilities was taken directly to the customer, which were evaluated prototype size in relation to child, orthostatic posture, gait practice, comfort, handling, risk of tipping, adjustments and effort to drive.

The test carried out under the supervision of responsible and physiotherapist, was the practice of walking on median roughness floors and flat floor with little or no inclination. By observing the child's movements and equipment involves the stress generated, taking into account the above mentioned, one can evaluate the prototype.

4 Final Considerations

It is necessary for all children, appropriate support to develop in society, but for a diplegic child, it is more difficult to make progress. Thus, the development of this paper presents a proposal for a child with diplegia have the satisfaction and well-being get around on their own, creating independence and autonomy.

Once analysis is conducted on key customer needs and project requirements through the House of Quality, an initial design was deta-lhada and prototyped through Benchmarking, assisting in the effectiveness of the product. The initial idea was to manufacture equipment in aluminum to make it as light as possible, however due to the high cost and difficulty in welding, was chosen the SAE 1020 steel, easy availability in the market, low cost compared to aluminum good mechanical strength.

Some elements of the device structure were submitted to analytical calculations in order to obtain the stresses and deformations acting, ensuring that the necessary strength is obtained. Preliminary tests were carried out on a first computer simulation throughout the structure, using the modules CAD/CAE software Solidworks. After making improvements, a second simulation was performed to determine maximum effort supported by the equipment. After analysis of these results and approval, a final prototype was developed in steel (Fig. 5). The prototype was tested by the user (Fig. 6) and approved by all stakeholders, as could perform the available functions expected.

Fig. 5 Final Prototype

Fig. 6 Prototype application. Test performance and analysis of the orthostatic posture

References

1. Paz, R.J.: The Persons with Disabilities in Brazil: Social Inclusion. As Pessoas Portadoras de Deficiência no Brasil: Inclusão Social. Universitária, João Pessoa (2006)
2. Brazilian Institute of Geography and Statistics.: Instituto Brasileiro de Geografia e Estatística (IBGE), http://www.ibge.gov.br
3. Mayston, M.J., Beattie, K., Gelkop, N.: The effect os treadmil training on function and fitness children with cerebral palsy: a preliminary study. Develop. Med. Child Neurol. **48** (2006)
4. Pereira, S.O.: Reabilitação de Pessoas com Deficiência no SUS: Elementos para um Debate Sobre Integralidade. Rehabilitation of Persons with Disabilities in the SUS: Elements for a Debate on Completeness 2009. vol. 113. UFB, Salvador (2009)
5. Cowan, D., Khan, Y.: Assistive technology for children with complex disabilities. Curr. Pediatr. **15**, 207–212 (2005)
6. Wintergold, A.: The use of standing supports for children with disabilities. APCP J. (2006)
7. Rozenfeld, H., et al.: Gestão de Desenvolvimento de Produtos: Uma Referência para a Melhoria do Processo. Development product management: a reference for process improvement. Saraiva, São Paulo (2006)
8. Vanzetti.: http://catalogo.vanzetti.com.br/index.php/europa-luxo
9. Expansão.: http://expansao.com/produtos/transfer
10. R82.: http://www.r82.com

Designing Accessible Course Registration for Users with Visual Impairments

Tanaya Joshi and Young Mi Choi

Abstract Visually impaired (VI) and blind users use accessibility features like type-to-speech software or Zoom Text, to navigate the internet. Accessibility features do not compensate for fundamental browsing experiences of understanding visual and informational hierarchy, skipping around, or skimming sections, leading to cognitive burden on the user. Despite growing interest in accessibility research, many websites are difficult for blind and VI users to navigate. With number of students in universities increasing, key processes, such as registration, have become web-based. Over 500,000 blind and VI students are enrolled in universities so it's imperative that they be able to register for classes efficiently and independently. The goal of this study is to improve the experience of adding, dropping, and changing grading format of classes, for blind and VI users. The new design will be tested against the existing one for usability, accessibility, and ease of use.

Keywords Human factors · Class registration · Interaction design · User experience design · User interface design · Blind · Visually impaired

1 Introduction

With the number of students in universities increasing many key processes, such as class registration, have become web-based. Visually impaired and blind users have a hard time navigating the web. They commonly use accessibility features such as browser-to-text speech software or zoom text in order to navigate the internet.

T. Joshi (✉) · Y.M. Choi
Georgia Institute of Technology, School of Industrial Design,
North Avenue NW, Atlanta, GA, USA
e-mail: tanayarjoshi@gmail.com

M. Soares et al. (eds.), *Advances in Ergonomics Modeling, Usability & Special Populations*, Advances in Intelligent Systems and Computing 486,
DOI 10.1007/978-3-319-41685-4_43

Despite the growing interest in accessibility research and laws to ensure web accessibility, a huge number of websites are difficult to navigate for blind and visually impaired users. Where rules and guidelines are set to address general accessibility issues, very few efforts are made to truly better the user experience of blind and visually impaired people. With over 500,000 blind and visually impaired students enrolled in universities, it's imperative that they be able to conduct administrative activities (e.g. register for classes) efficiently and independently [1]. At the Georgia Institute of Technology selecting the right classes during registration involves using a web based interface along with a possible visit with an advisor. It can be a cumbersome process even for students with normal vision. Adding classes, dropping classes or changing other attributes are difficult tasks for blind users to perform even with screen readers or use of other assistive technologies. The objective of this project is to design a class registration system at Georgia Institute of Technology that will enhance usability for adding, dropping, or changing grading method of classes for blind and visually impaired users.

2 Significance of the Problem

Blind and visually impaired users access the internet through screen readers and zoom text on their computers. A lot of websites are inaccessible to blind and visually impaired users because they're not built with these features in mind. This includes common class registration site at Georgia Tech called OSCAR (www.oscar.gatech.edu). OSCAR is Georgia Tech's portal for registration which contains information such as the catalog of class offerings, information on financial aid, and transfer equivalencies. Its inaccessible design makes it hard for blind and sighted users to sign up for classes. The features that allow classes to be added, dropped or changed are poorly designed.

3 Specific Aims

The aim of this study is to create an improved experience for adding, dropping and changing classes for blind and visually impaired students at Georgia Tech. A variety of literature and usability studies will be conducted to get context to the topic to find out how blind people use the internet, what regulations are in place to ensure web usability for them, if these regulations are enforced, etc. Surveys and interviews with students would serve as a baseline to understand the current registration processes across Georgia Tech. Surveys and interviews with advisors would serve as a additional insight from a different perspective. Conversations with blind and visually impaired students as well as the Office of Disability services will help understand how blind and visually impaired students register for classes. This initial study will establish a foundation to start prototyping. The new design will be tested against the existing one for accessibility, effectiveness, efficiency, and user satisfaction.

4 Background

Legal blindness using the Snellen methodology [2] is defined as those with central visual acuity of 20/200 or less in the best eye with correction, or a visual field of 20° or less On newer charts, such as the Bailey-Lovie [3] or the Early Treatment Diabetic Retinopathy Study (ETDRS) [4], legal blindness is defined as those who are unable to read any of the letters on the 20/100 line. People with total blindness are defined as those who cannot see with either eye or have a visual acuity of 20/400 or worse (visual field of less than 10°) [5]. As of 2012, 2.5 million individuals in the United States are listed as legally blind or visually impaired [6].

Visually impaired and blind users interact differently with web-based tools than non-visually impaired users. Blind people have traditionally been dependent on Braille or audio books to gather information. Information gathered from these sources tends to be outdated or expensive, making them less favorable. Much more up to date information can be gathered from the internet. This medium can be made available to blind and visually impaired users through screen-readers. However, it takes quite some time to learn how to use screen readers effectively [7]. Research shows that blind and visually impaired users' web experience suffers from inability to scan pages [8]. This is important since approaching web pages in a top to bottom manner leads to a huge cognitive burden [9]. Additionally, web pages can contain complicated page layouts that result in ambiguous screen-reader feedback, mispronunciations, and cognitive overload on the user [8]. Web content that is visual in nature or based on perception can be particularly inaccessible [10]. The alternate textual descriptions provided for this kind of content also tends to be monotonous and information heavy. For example, if we were reading a newspaper to a blind user, we wouldn't read everything, we would skim the important parts [10].

Web accessibility problems lie outside screen-readers. Oftentimes, the websites are coded to follow a checklist of regulations yet still remain inaccessible. A study of 50 popular websites showed that over half of them are either inaccessible or somewhat accessible [11]. Pages can be particularly inaccessible in cases where web content is visual or based on perception [10]. For example, alternative text is required to accompany each image, but this is often treated lightly and meaningless tags are used. Accessibility checkers don't verify that these tags are appropriate, only that they exist [12]. So there could be an image of the mountains embedded with an HTML but with a description that reads "a432iodvlq330." The screen reader will catch that and relay "Image a432iodvlq330" as the audio output, instead of something relevant.

A number of guidelines have been developed to ensure web accessibility for blind and visually impaired users. The Web Content Accessibility Guidelines (WCAG) is recognized as the primary design principles on Web accessibility, though it's not universally applicable like ISO standards. WCAG are comprised of 4 guidelines and 18 checkpoints. Listed are the guidelines:

Principle 1: Perceivable—Information and user interface components must be presentable to users in ways they can perceive.
Principle 2: Operable—User interface components and navigation must be operable.
Principle 3: Understandable—Information and the operation of user interface must be understandable.
Principle 4: Robust—Content must be robust enough that it can be interpreted reliably by a wide variety of user agents, including assistive technologies.

Access Board's Section 508 Standards (36 CFR Part 1194) was set in place to ensure that users with disabilities "have access to federal information technologies and properties" [7]. Products covered under this are to comply with all provisions of the standards. They are set in place to, not to prevent design or technology from moving forward, but to remain accessible to people with disabilities [13]. These rules ask for reasonable concessions to be made such as using plain text instead of graphic text, having a feature to enlarge text (though graphics may become blurry), adding tags to images, applying reasonable amount of contrast, not relying on color to convey information, etc. However, accessibility tools and guidelines are not adequate for insuring accessibility for disabled users.

As of 2013, there were over 500,000 blind and/or visually impaired people with a bachelor's degree or higher [1]. Most, if not all, universities use websites to communicate academic and administrative information. On the academic front, professors are referring to the internet to communicate with students [14]. Most universities have online portals for administrative duties such as paying fees, registering for meal plans, looking up or registering classes. As of 2011, 42 percent of institutions provide priority class registrations for students with disabilities [15].

Assistive technology can give students who are blind or have low vision support in all academic areas. The selection of devices and software is contingent upon a variety of factors and students may need to utilize multiple pieces of technology throughout their program of study [5]. Mallory Joynt, coordinator at the Disability Services office was contacted in order to get specific context in the case of Georgia Tech. It was found out that students either use Voice Over Text feature or get assistance to register for classes, but details of it are unknown [16]. The Voice Over Text, or Voice Over feature converts text to speech on multiple electronic devices. Listed here are a few examples:

Braille displays: Display information on a computer screen by raising and lowering combinations of braille pins. It typically sits underneath the user's keyboard and refreshes in real time as the user moves the cursor on the screen. The main disadvantages of this technology are the slow reading speed and that it doesn't allow for a hands-free experience. On the plus side, it is portable, it allows access to information which would've been otherwise unavailable in braille, it is easy for users to create and edit documents easily, it is reliable, easy to set up, it interfaces well with other devices, and has a good battery life [17].

Screen readers: Software programs that interface with the computer's operating system and provides the user full control over reading and interacting with their computer (e.g. using a navigation menu, highlighting text, using a spell checker, etc.). Jobs Access with Speech (JAWS) is arguably the most widely used screen-reading program. Screen Readers are especially beneficial in allowing blind people use computers, create documents using word processors, read articles on the internet, write emails, social network, play games, etc. Screen readers have also allowed musicians to use audio editing software to record, edit, and save song samples. However, screen readers can be dry and monotonous sounding, users can't skim using screen readers, and it is time consuming [18]. More of the disadvantages are previously discussed.

Screen magnification: Allow the user to enlarge the graphic, media, and text on a computer screen. The user can control what gets magnified (e.g. text cursor, mouse pointer, icons, title bars, etc.). ZoomText is an example of a popular screen-reading and magnification program that provides students with access to visual and auditory translation for what's appearing on their computer screen. For visually impaired users, screen magnifiers are great options since they are customizable, have high contrast modes, and tracking enhancements. However, images aren't always clear as magnification increases, it requires training, and how much you can magnify is variable based on what the user is accessing [19].

Defining and assessing user experience, usability, and accessibility: User experience refers to the user's ability to communicate with a design [20]. It is considered to be particularly helpful in evaluating the effectiveness of a design [21]. A positive experience is highly valued by a user and the designer because users interact with products and connect with them by acting, thinking and discussing about them in a positive manner [22].

Where user experience looks at the interaction, thoughts, feelings, and reactions, usability is the user's ability to carry out the task successfully [23]. It's important to assess the usability as well as the overall user experience. According to ISO 9241, usability testing is determined by effectiveness (how well a user can perform given tasks accurately and completely), efficiency (how quickly a user can perform given tasks), and satisfaction (how much users like the product) [24].

Accessibility in web development is a standard practice designed so that information is available to all people, regardless of their disability [7]. For example, having the right amount of contrast between background and text for color blind people, captioning videos for deaf people, adding HTML tags to images for blind people. Like universal design considerations are made when designing physical objects, it's important to make considerations for accessibility in web design as well. A great resource for these standards is The Web Content Accessibility Guidelines (WCAG) [25].

An efficient way to assess usability within design is through Jakob Nielsen's principles for interaction design [26]. This is a refined list, based on an analysis of 249 usability problems [27]. Below are the principles:

- Visibility of system status: System should keep user informed on status through reasonable feedback and time
- Match between system and the real world: System should speak in a way that's known to the user (e.g. using real-world conventions instead of system-oriented terms)
- User control and freedom: Clearly marked exit to leave unwanted screens
- Consistency and standards: Consistency in using standard symbols and language so to not confuse the user and keep their experience consistent
- Error prevention: Carefully designed system that checks for and eliminates error-prone conditions
- Recognition rather than recall: Minimize the need to memorize information
- Help users recognize, diagnose, and recover from errors: Suggest constructive solutions in plain language so users can troubleshoot
- Help and documentation: Provide documentation and help by listing out steps and keeping it simple

Other similar sets of principles for creating good web interactions exist. Scott Berkun of Microsoft Corporation explains the human factors of user experience through his web article series [28]. Work flow is a silent, but key player in making sure the user experience is good. The irony of flow is that when it is successfully established, the users are unaware of it. Users only notice flow, or more precisely, the lack of flow, when it is poorly executed. To properly execute flow, the site must be designed from the perspective of the user. Wireframes must be done by putting yourself in the user's shoes to evaluate what needs to be added to or taken away from the system.

The best way to get to the heart of web accessibility issues through usability testing, since current website checkers cannot be relied on [12]. However, there has been little agreement about the best methods for determining accessibility of web pages [7]. Studies show that several research methodologies will need to be implemented in order to ensure that the final product is truly accessible for blind and visually impaired users [29]. Research shows that testing methods which found most errors involved screen readers [7].

Market Research: Survey of Class Offering Sites in Other Universities: The intent of this market research was to survey registration-related websites and to see how different universities are approaching content, density of information, navigational UIs, and visual language. Successful elements include (1) Hierarchy established through font sizes, color, headings, subheadings, links, and charts. (2) Consistent visual language, which makes it easy to predict and understand web pages. (3) Important information made accessible. (4) Quick to navigate. (5) Pop-ups in place of new windows or tabs. (6) Contrasting colors that help make navigation easy. (7) Systematic organization of content.

Unsuccessful elements include (1) Numerous subheadings in the navigation menus. (2) Dated looking sites (3) Long pages, dense with information. (4) Unclear navigation. (5) Too many navigation options (Table 1).

Table 1 Outline of features from features from different sites that were researched

	Stanford	MIT	Pratt Institute	UT Austin	Carnegie Mellon
Evident hierarchy	x	x	x	x	x
Dense with information	x			x	
Navigation using ribbons		x		x	
Consistent visual language			x		x

5 Proposed Design

When registering for classes at Georgia Tech, students have to go through OSCAR. Currently, blind and visually impaired students sign up with guidance from someone in the ADAPTS office (Georgia Tech's center for Disability Services), but are generally left to themselves when it comes to adding, dropping or changing classes. The design aims to create a successful experience when adding, dropping, and changing grading formats of classes, allowing blind and visually impaired users to register independently.

This redesign is intended to be universal to meet the needs of all able-bodied, visually impaired, and blind users. Through research, user interviews, and simulations, it was found that text-to-voice allow users, who otherwise would not be able to utilize a website, to seamlessly navigate and manipulate a website. Unfortunately, the present state of OSCAR is not user-friendly when it comes to text-to-voice functionality. Therefore, one of the main drivers for the redesign was to accommodate the visually impaired and blind population by taking advantage of the text-to-voice capabilities. To make this possible, HTML tags will be embedded, making navigation through different elements clear and easy.

The redesign includes a streamlined sense of flow so that each page is simple and contains only the necessary information to decrease the cognitive workload and to be accessible via text-to-voice. Where in OSCAR there are multiple links and steps to getting through registration, the proposed system is clutter, helping the user understand the workflow easily.

Figure 1 shows an overall layout of classes under a selected major. In this case, it is Industrial Design. This layout allows the user to sort classes based on different identifiers (title, hours, credits). The options under "show" (all, studio, humanities, etc.) lets users filter classes as well, allowing for quicker access to pertinent information. This design houses all sections of class under the title (Fig. 2), so users can collapse it if they want more information. It is a particularly useful since it mimics skimming.

The current system requires users to go to a new page to make changes to their class selection, and to go back to the registration page if they want information on a class. The proposed system cuts down the number of screen changes and keeps all activities on the same page. Figure 3 shows what users see once they register for classes. From here, users can click on active hyperlinks to read about the class (Fig. 4), change the number of hours they're signed up for (Fig. 5), change the grading format (Fig. 6), or drop the class (Fig. 7). These steps require two levels of affirmation from the user—one when they conduct the action on the pop up and another when they're done and want to exit the screen. This way, if the user makes changes by accident, they can hit "Cancel" instead of "Submit Changes" to avoid saving the mistake.

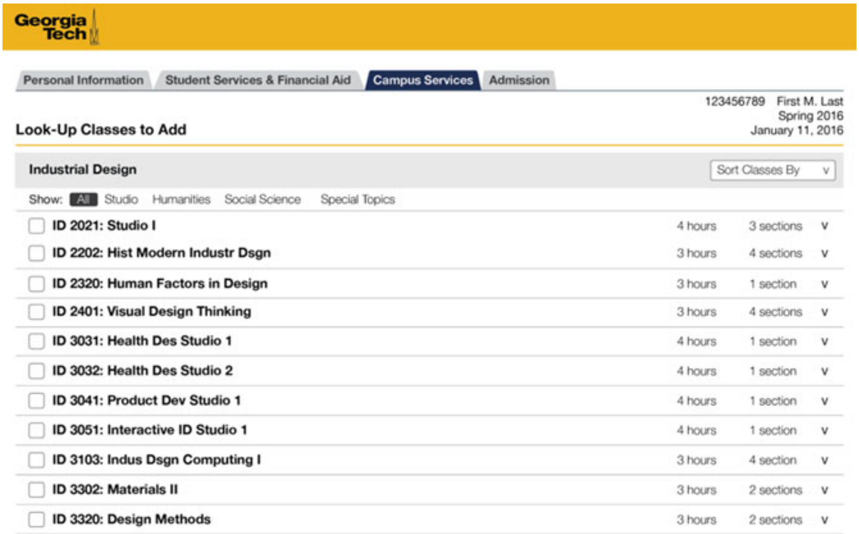


Fig. 1 Proposed layout for displaying classes under the major, industrial design

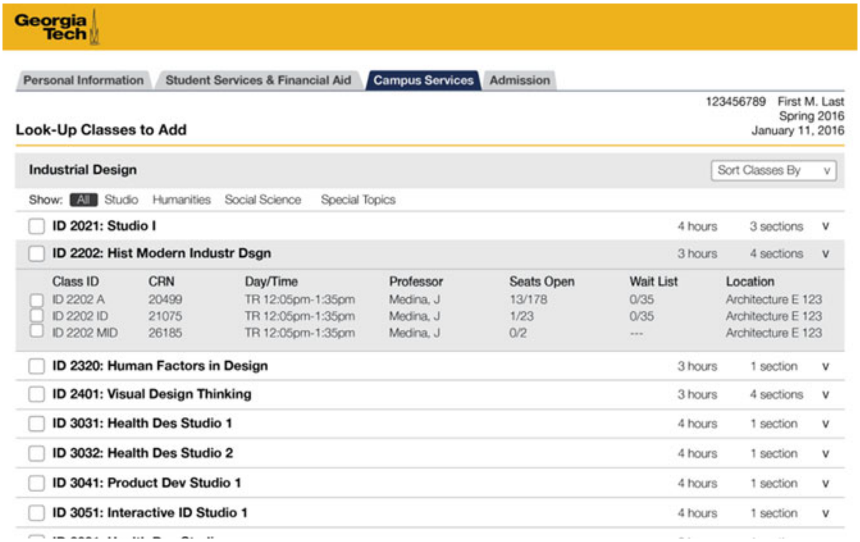


Fig. 2 Proposed layout for class offering

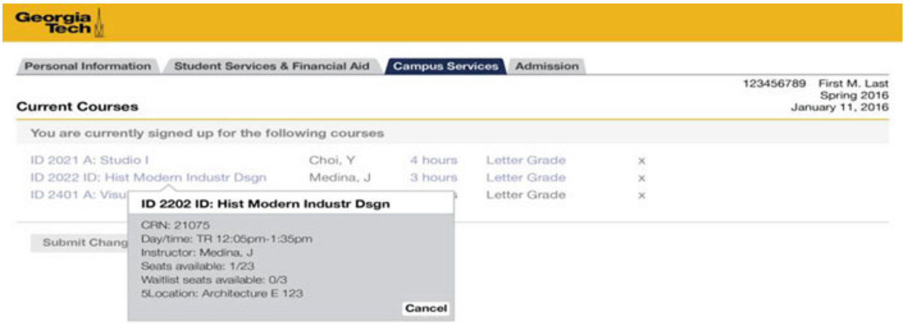


Fig. 3 Users can get more information, change number of hours, method of grading, and drop classes

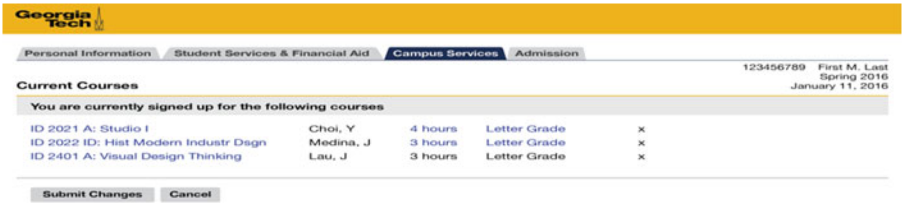


Fig. 4 Click class title to get additional information

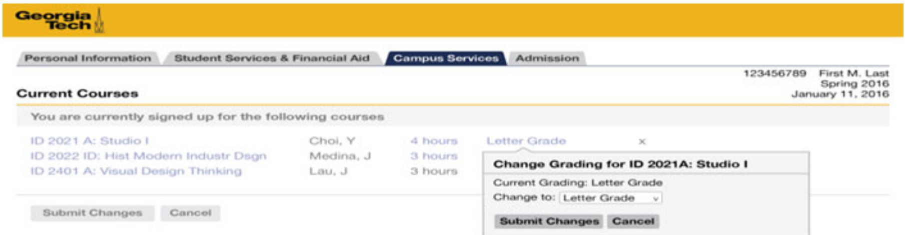


Fig. 5 Click number of hours to change the value

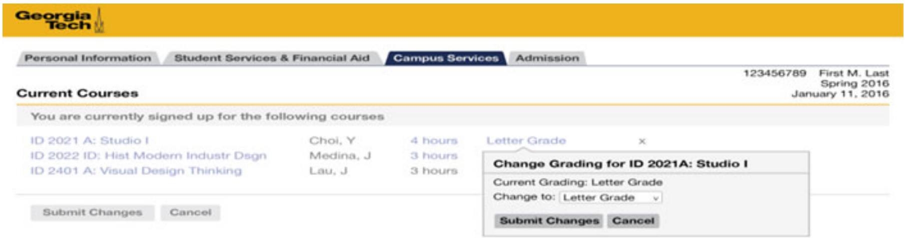


Fig. 6 Click grading format to change value

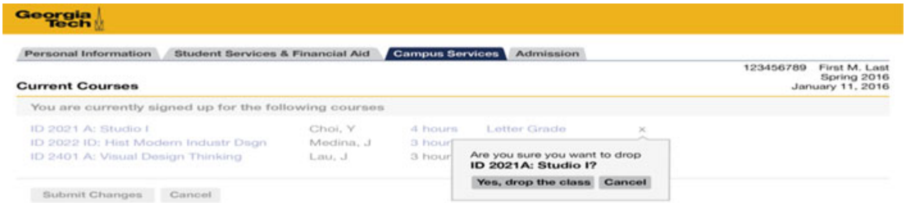


Fig. 7 Click the 'x' to drop class. Click "Yes, drop the class" to drop. This pop up is designed with colloquial verbiage to ensure simple communication

6 Discussion

Usability tasks have to be designed while considering how users want to interact with the product. The tasks should also be representative of real tasks that the users will be conducting. Instead of telling people how to use the prototype, it will be more efficient to give them a set of tests that they can then carry out [30]. Furthermore, it will help to have tasks that are designed around potential usability problems since the more problems found in the limited time, the more successful this test will be. It is important to develop a procedure that will find the serious usability problems [30].

For this test, users will be asked to sign up for a list of specified classes in the existing system. This is important since students have to plan their classes before they register. They will then be asked to drop one of them, change the hours for a class, and change the grading format for a class. This is important because often times, classes open up so students have to change their schedule by adding/dropping a class. Or students come back later in the semester to drop a course.

Either way, if a student fails at conducting the task, he/she has to go to the Registrar and make a case to correct the mistake, especially if it's part the registration time frame. At the end of it, they will be given the USE questionnaire [31] to fill out. This questionnaire gives them a scale to rate the design's usability and easy of use, and their satisfaction. It also gives them room to make comments, which is particularly insightful since users don't always think out loud. This same exercise will be repeated for the proposed system.

If the responses toward the two designs are significantly different, then there will be a clear solution as to which is the better alternative. However, if the responses are same, then there is no reason to replace the current system since it's already implemented and it generated the same results. For the new design, I expect users to rate it higher on the USE Questionnaire. I also expect to go through the test faster and more efficiently.

MORAE software will be used as a testing tool. It is a software designed to facilitate usability research from design study to data analysis and can support a variety of research types. The Recorder tool will allow audio and video capture as well as the user and his/her on-screen activity, including keyboard strokes and mouse clicks. The Observer tool allows for one ore more computers to observe the real-time statistics that are being recorded in Recorder [32].

References

1. National Federation of the Blind.: Blindness statistics. September 2015 [cited 1 Nov 2015]; Statistical Facts about Blindness in the United States]
2. Sue, S.: Test distance vision using a Snellen chart. Commun. Eye Health J. **20**(63)
3. Bailey, I.L., Lovie, J.E.: The design and use of a new near-vision chart. Optom. Vis. Sci. **57** (6), 378–387 (1980)
4. Group, E.T.D.R.S.R.: Early photocoagulation for diabetic retinopathy: ETDRS report number 9. Ophthalmology **98**(5), 766–785 (1991)
5. Chris Danielson, M.M.: A guide to visual disabilities: how colleges help visually impaired students succeed, 1 Sept 2015. Available from http://www.affordablecollegesonline.org/colleges-helping-visually-impaired-students/
6. Paisios, N.: Mobile accessibility tools for the visually impaired. Courant Institute of Mathematical Sciences, New York (2012)
7. Mankoff, J., Fait, H., Tran, T.: Is your web page accessible? A comparative study of methods for assessing web page accessibility for the blind. In: Proceedings of the SIGCHI Conference on Human Factors in Computing Systems. ACM (2005)
8. Babu, R., Singh, R.: Evaluation of web accessibility and usability from blind user's perspective: the context of online assessment. In: AMCIS 2009 Proceedings, p. 623 (2009)
9. Herrman, J.: Giz explains: how blind people see the internet. 2010 August 24, 2010; Available from www.gizmodo.com/5620079/giz-explains-how-blind-people-see-the-internet
10. Di Blas, N., Paolini, P., Speroni, M.: Usable accessibility to the web for blind users. In: Proceedings of 8th ERCIM Workshop: User Interfaces for All, Vienna, Citeseer (2004)
11. Sullivan, T., Matson, R.: Barriers to use: usability and content accessibility on the web's most popular sites. In: Proceedings on the 2000 Conference on Universal Usability. ACM (2000)
12. Takagi, H., et al.: Accessibility designer: visualizing usability for the blind. In: ACM SIGACCESS Accessibility and Computing. ACM (2004)

13. Register, O.: Electronic code of federal regulations. 2014 September 14, 2015 September 10, 2015]; Available from http://www.ecfr.gov/cgi-bin/text-idx?node=pt36.3.1194&rgn=div5
14. Robin, B.R., McNeil, S.G.: Creating a course-based web site in a university environment. Comput. Geosci. **23**(5), 563–572 (1997)
15. Raue, K., Lewis, L.: Students with disabilities at degree-granting postsecondary institutions. First Look. NCES 2011-018. National Center for Education Statistics (2011)
16. Joynt, M.: Data for visually impaired students. In: Saboo, P. (ed.) (2015)
17. Home, H.C.: Use of Braille Displays. RNIB Centre for Accessible Information, Birmingham (2011)
18. Joey. G.: Advantages and disadvantages of using a screen reader instead of braille. Blind Street (2012)
19. Anderson Fran Mary, M.S., Current technology solutions for students who are blind/visually impaired. Blind and Visually Impaired Student Fund (BVIS), Oregon
20. Sánchez Sierra, J., de Togores, J.S.R.: Designing mobile apps for visually impaired and blind users, p. 6
21. Hassenzahl, M., Tractinsky, N.: User experienceA research agenda. Behav. Inf. Technol. **25** (2), 91–97 (2006)
22. Koskinen, I., Battarbee, K., Mattelmäki, T.: Empathic Design. IT Press, New York (2003)
23. Albert, W., Tullis, T.: Measuring the user experience: collecting, analyzing, and presenting usability metrics. Elsevier Science, London (2013)
24. Standardization, I.O.F., ISO 9241-11.: 1998: ergonomic requirements for office work with visual display terminals (VDTs)—part 11: guidance on usability. International Organization for Standardization (1998)
25. Ben Caldwell, M.C.: Web Content Accessibility Guidelines (WCAG), 2.0, Loretta Guarino Reid, Gregg Vanderheiden (2008)
26. Nielsen, J.: Ten usability heuristics. (2005). http://www.nngroup.com/articles/ten-usability-heuristics/(acc-essed December 19, 2013)
27. Nielsen, J.: Enhancing the explanatory power of usability heuristics. In: Proceedings of the SIGCHI Conference on Human Factors in Computing Systems. ACM (1994)
28. Berkun, S.: The human factor in user interface design (2000)
29. de Souza, E.R., de Freitas, S.F.: Dosvox usability: recommendations for improving interaction of blind people with the web using the system. Work **41**(Suppl 1), 3443–3448 (2012)
30. Dumas, J.S., Redish, J.: A practical guide to usability testing. Intellect Books, Glasgow (1999)
31. Lund, A.M.: Measuring usability with the USE questionnaire. STC Usability SIG Newslett. **8** (2) (2001)
32. Corporation, T.: Morae 3. Morae 1995–2015 [cited 29 Feb 2016]

Augmented Reality Based Social Stories Training System for Promoting the Social Skills of Children with Autism

Chi-Hsuan Chung and Chien-Hsu Chen

Abstract Profound social reciprocity deficits are a core feature of the autism spectrum disorders. Children with autism often lack appropriate social skills when they need to interact with other people. A social stories training is one type of children-specific intervention for teaching social skills. It helps learn social skills through combination of visual and verbal cues. We use augmented reality (AR) technologies to visually conceptualize the social stories. Interactive social stories are played using several tangible markers and AR technologies that overlays the markers with corresponding virtual images. The new way to interpret social stories demonstrates an improvement of attraction and enhances effects of social skills training. Finally, We have a prototype for the social skill—"greeting" and an initial pilot study to support the therapy of high-functioning autism children.

Keywords High-functioning autism · Augmented reality · Social skill

1 Introduction

Autism is a spectrum neurodevelopmental disorder. The severity and range of disordered including intelligence, communication skills and behaviors vary within wide limits, ranging from very low to very high functioning. High-functioning autism children often have milder symptoms than those low-functioning ones and possess better potential and developmental possibility in comparison to adults with autism. Despite this, they still face the same problem in social interactions with properly.

C.-H. Chung (✉) · C.-H. Chen
Department of Industrial Design, National Cheng Kung University,
No.1, University Road, Tainan, Taiwan
e-mail: michael33597@hotmail.com

C.-H. Chen
e-mail: chenhsu@mail.ncku.edu.tw

M. Soares et al. (eds.), *Advances in Ergonomics Modeling, Usability & Special Populations*, Advances in Intelligent Systems and Computing 486,
DOI 10.1007/978-3-319-41685-4_44

Profound social interactive deficits are a core feature of the autism spectrum disorders. Common deficits include initiating and terminating interactions, learning the interests of others, joining social groups, eyes contacting, turn taking, recognizing facial expressions and nonverbal social cues understanding [1]. Children with autism often lack appropriate social skills when they need to interact with other people, and then result in a frustrated and embarrassed situation.

A simple but important social skill is "greeting". Greeting to other people like parents or friends consists of many regular manners and needs autistic children to learn and practice. They have challenges saying "hi" to people who they loved and also struggled to interact appropriately with them. Owing to lake of social skills, children may act out aggressively during misunderstandings or stare at people not knowing what to do or say [2].

Interventions for individuals with autism usually begin early in life and are typically aimed at teaching social and interactive strategies. A social skills training (SST) is one type of child-specific intervention [3]. This intervention involves teaching specific skills (e.g., maintaining eye contact, initiating conversation) through behavioral and social learning techniques [4]. One of the common training methods is using visual supports such as images and drawings because of the reason that autistic people often have strengths in the visual spectrum; these individuals excel in response to visual interventions [5]. Visual supports have been applied in developing visual schedules and social stories to help deal with daily lives. Now, most of the available social skills training tools use visual supports as a main interventional method.

Social stories are one type of the social skills training therapies. They are short stories constructed to mention, interpret, and reflect on social situations that individuals with autism are not good at. Social stories can improve autism children' social skills through combination of visual and verbal cues. They supply a visual support at each step in specific social behavior so the child can minimize those factors identified as potentially confusing during interaction to provide accurate information and describe appropriate responses.

Social stories have also been proved effective in teaching greeting skills to individuals with autism [6]. The research successfully taught a girl and a boy, they all with autism, how to share and greet peers. The researchers found an increase in greetings and sharing by the participants. Another research also certified the effect of social stories used to instruct how to greet family children with friendly behaviors by an autistic patient [2].

Augmented reality (AR) is a technique that devotes to extend the physical world with digital information [7]. Superimposing digital contents onto the real world, we can view and even interact in time with virtual messages, characters or other information that have three-dimensions in the real-life environment. Although AR technologies have not been a novel issue, they still keep a broader development space for autism treating. Preliminary researches have shown positive adoption and beneficial effects of AR technologies in general cognitive rehabilitation [8] and psychological disorder treatment [9]. The potential of augmented reality to be applied to the autism intervention and be connected to social stories are full of diverse possibility.

We aims to provide a tool using augmented reality and social stories for therapists, special education teachers or even parents to help children on the autistic spectrum learn the social skills of greeting. There are some reasons why AR technologies may assist children with autism to establish improved social skills with social stories. Augmented reality supports various forms of social stories by creating easy-to-operate simulative social situations that the children with autism are familiar with. According to certain social story, virtual avatars will show correct social behaviors on the specific social stage through different motion and sound in the real world. AR technologies also have the strength to offer three-dimensions image or animation, which is more real than conventional 2D image or video. Besides, using tangible tools as AR markers completely avoids the use of a computer screen. Individuals with autism can move, change or combine different markers to get an immediate feedback effect on AR image which corresponds to different social story. AR technologies may bring benefit opportunities beyond professional social stories therapeutic contexts. Our objective is that develop a new way to interpret social stories for demonstrating an improvement of attraction and enhancing effects of social skills training among children with autism through importing advanced augmented reality technology.

This is a preliminary study of a new AR social stories training system design. In the research, we chose "greeting" as a template from numerous social behaviors. The reasons are that we would like to find an appropriate social situation that is common and basic in autism community and has had many existing social story scripts; as a result, we can test more children with autism under the same story and gather or modify story scripts more easily, so the pilot study may work efficiently and the data we get can be compiled or analyzed with the same view.

2 Related Works

Individuals with autism and their caregivers consider social skills as the primary domain where they need support from technology [10]. Several attempts have been made to know not only are software and technologies well received among individuals with autism, but research also supports the effectiveness of computer-based training for teaching a variety of skills to those with autism. Some examples such as using virtual avatars like "Baldi" [11] to teach autistic children language skills with a virtual head or applying virtual environment as a tool to improve social skills under the situation where subjects with autism want to find a seat to sit [12]. Besides, tangible interface is also a technique that enables autistic patients to control the system in an intuitive way and provide immediate haptic feedback during the interaction, which was used to encourage social communication in "Augmented Knight's Castle [13]."

Although augmented reality technology has played important roles of assisting individuals with autism in some studies, there has been relatively little research into potential possibilities of AR in social stories training for children with autism. For what concerns for using AR as a mediate tool when treating autism, some works has been offered in literature. Zhen et al. [14] described an augmented toy set to enhance the ability of pretend play for autistic children. Its operations are similar to our approach, but we have animated effects in addition to static displays. Mosoco [15] is a mobile assistive application that connects AR technologies with visual supports to help autistic children practice social skills. Our work shares similar ideas of increasing comprehensions of social skills by using visual presentations, but we have more selective contents to face different problems by changing different social story. Alessandrini et al. [16] introduced an audio-augmented paper to support the process when using social stories intervention for low-functioning autism children. The issue about social stories is the same compared with our study, but the target behind is different. Our work devotes to use AR technologies to create a new form of social stories other than puts the focus on the caregivers.

3 Method

For bringing out AR contents, we have to prepare a conventional social story text in advance. Our social stories text version about greeting referred to several websites of different autism associations [17, 18] and a book written by Carol Gray [19], who is the initiator of social stories. The greeting issue we wanted to solve can divide into three parts: (1) greeting with parents, (2) greeting with friends, (3) greeting with strangers, so we created three stories for each other. The all stories we edited will be tested simultaneously to teach children with autism different social behaviors when they greet to different people. In our social stories, we had the social skills lessons as below:

(1) Greet with parents: say hi or hello, kiss, and give a hug.
(2) Greet with friends: say hi or hello, wave, look at face, and call name.
(3) Greet with strangers: say hi or hello, ask names, introduce self, shake hands, and nod head.

Once we have story texts, the next thing for transforming them into AR versions is to do an analysis. We followed some guidelines according to the developer Carol Gray [19] to find used sentence types in our social stories. Four sentence types will be needed especially. They are: (1) descriptive sentence, (2) perspective sentence, (3) affirmative sentence, and (4) coach sentence (suggested responses for the audience, responses for his or her team, and self-coaching statements.) The descriptive sentences usually have the most information to construct an AR story. It is not all social stories have all types of sentence, but the descriptive sentence type is required certainly. Table 1 shows the four sentence types below.

Table 1 Four sentence types that we need to use involved in a social story

Sentence type	Function	Example
Descriptive	Objective statements of fact or the information that "everyone knows"	Most of the time my friends will say hi or wave to me when they see me
Perspective	Describe the thoughts, feelings, and beliefs of other people	Saying hi to friends is fun! People like me when I say hello
Affirmative	Enhance the meaning of surrounding statements	Everyone say hi to friends when they see them
Coach	Guide the behaviour of the audience or the members of team	When I see my friend I will try my best to wave or say hi

Table 2 A framework that transforms a social story into AR version

Sentence type	Relevant "wh" factors	AR social stories elements
Descriptive	What is happening?	Scripts
	Where a situation occurs?	Background
	When a situation occurs?	Background
	Who is involved?	Model
Perspective	Why should I do?	Narration
Affirmative		
Coach	How should I do?	Scripts

We also have to define "5W1H" questions to apply for the contents of AR versions. It means what, where, when, who, why, and how. The six questions can be answered by studying the four sentence types above. After this process, we can correspond the answers to the elements used to build a full AR social story. The relations between correspondences are given in Table 2. By operating this framework, we got useful elements for creating our "greeting" AR social stories as Table 3.

After we have known the elements needed in our AR system through the framework. In this part we will describe the design of the AR system in details. We would like to use a tangible approach for controlling the displays of AR animations. Marker-based tracking that is commonly used in AR applications can achieve our

Table 3 Three greeting AR social stories elements

Social situation	Story elements
Greet with parents	A home background, two 3D models (autistic child and Mom or Dad), story scripts and a piece of narration sound recording
Greet with friends	A school background, two 3D models (autistic child and friend), story scripts and a piece of narration sound recording
Greet with strangers	A community background, two 3D models (autistic child and stranger), story scripts and a piece of narration sound recording

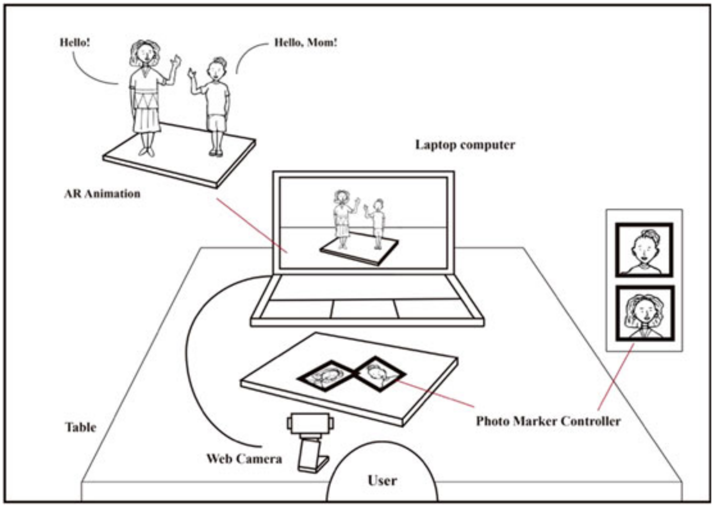


Fig. 1 The AR system diagram

goal and provide a more well understand human-computer interface to children with autism.

The full system includes a laptop computer, a web camera and several markers (see Fig. 1). The system applies photos of autistic patients, parents, friends and strangers to the pictures of markers that are printed on the sheets of paper. A web camera (Logitech Carl Zeiss Tessar HD 1080p) is set nearby the markers to recognize the presence of a sheet. A laptop computer is connected to the web camera via USB. It will distinguish the marker through reading a code assigned to each one which is recorded by the web camera and then call a corresponding 3D figure model to cover the marker on the screen. Besides, different markers can be put together to trigger social stories animations between 3D figure models that the markers represent (autistic child with parents, autistic child with friend, autistic child with stranger.)

4 Results

Our framework displays an effective method to transform a conventional social story text into an AR version. Once it is demonstrated that AR technologies play a positive impact in supporting social stories of children with autism, more contents or social situations could be transformed to enhance the quality of all system. The open framework can also be used and refined by any people. We expect to explore various possibilities between social stories and AR technologies, and encourage sharing ideas of designs for those autistic children who we care about.

Fig. 2 The prototype screenshot

The prototype reveals a social situation about greeting with Mom for autism children. Figure 2 shows an image that was a screenshot from the view of a web camera. The virtual figure Mom and virtual figure autism child are waving their hands toward each other. Their animated actions are according to prepared social story script (Appendix, A-1) and accompanied by verbal illustration of the story text. The other two greeting social situations that include “greeting with friend” and “greeting with stranger” have the same form but different contents. Choosing appropriate matches of two markers among several different ones corresponding focal social situations is the operation of performing social stories. Children with autism can view social stories composed of animate virtual characters and vocal illustrations repeatedly, and then learn social skills based on their special needs.

Besides, a full user scenario also includes an evaluation that will compare the subject’s greeting behaviors before and after the intervention afterwards. A person who is familiar with the autism subject will be invited to participate in the study during the period of intervention to help the evaluation and make subject feel more comfortable in an unfamiliar environment.

5 Conclusion and Discussion

We are currently developing the prototype and accessing to our subjects continuously. The prototype will be an augmented reality social stories system for guiding “greeting” social skills to children with autism. According to different “greeting” social situations, autistic child will be requested to select two appropriate photos (markers) and then watch the screen to view a social story that is showed by those two virtual characters corresponding the photos. Through the research, we expect to make three main contributions as below, which will benefit the therapeutic or educational setting and researchers from AR or human computer interaction field:

(1) Give conventional social stories an opportunity to get a new style and appearance by introducing AR technologies.
(2) Understand user behaviors, practical effects and hidden deficits when children with autism interact with an AR environment and then form useful design guidelines for future studies.
(3) Raise a framework to support later researchers to transform a conventional social story into AR type social story.

The research is just a pilot study for AR social stories; we still have more ideas in our mind. Several ongoing plans are illustrated below:

(1) We use faces of participants to make the appearances of 3D virtual characters and take pictures for them to produce AR markers. Autism subjects and other people who are participating in the research will have their own photos (markers) and virtual models. Through this design, child with autism can look himself or herself in the AR social stories as a main role. We referred to a research about using masks to augment different facial expressions for assisting children with autism in learning expressions on their faces [20]. The system will be more immersive and attractive to them.
(2) We prepare various backgrounds (home, classroom, etc.) for different social situations. An AR marker that used the background photo triggers a 3D virtual background model and then the characters' markers will be put on the background marker so users can get a view of virtual roles interacting in the virtual background. The social story can fulfill the social situation more closely and enhance immersion.
(3) We plan to give the process of operating the system several new mechanisms. It will be like a game for autism children that they play social stories one after another. A set of AR social stories will be constructed corresponding social deficits of the subject appropriately and be separated into different levels according to the complexity of the social skills that the stories focus on. Children can challenge and practice social skills systematically. The study process will also get more fun and attractive.

A series of usability study will conduct to validate our design and get more information to improve and refine the system. More details about formal evaluation are discussed with several experts and then implemented the new functionalities suggested in the next future.

Appendix: Social Stories

A.1 Greet with Mom

There are many ways to greet someone.

Sometimes I can say, “Hello!” or “Hi!” It’s a great way to start a conversation and a good way to make new friends. I love to greet people because it makes me happy; it also makes the other people happy. They smile and respond to the greeting. I can also use sign language to greet someone!

When I see Mommy I can say “Hello!” to her.

Sometimes I can kiss her forehead, or even give her a hug if I want.

Saying hi to Mom is fun and a short hug also means “Hello!” Mom likes it when I greet her.

Most of the time she will say hi or give me a hug back when I greet her, this is a friendly and loving thing.

A.2 Greet with Friends

There are many ways to greet someone.

Sometimes I can say, “Hello!” or “Hi!” It’s a great way to start a conversation and a good way to make new friends. I love to greet people because it makes me happy; it also makes the other people happy. They smile and respond to the greeting. I can also use sign language to greet someone!

When I see my friend I will try my best to wave or say hi. When I say hi I can wave or use my words. I can say hi and than the person’s name.

Sometimes it is hard to say hello to friends but I will try my best to look at my friend’s face and wave or say hi.

Saying hi to friends is fun! People like me when I say hello.

Most of the time my friends will say hi or wave to me when they see me. I can try to say hi and wave back when this happens. Everyone say hi to friends when they see them.

A.3 Greet with Strangers

There are many ways to greet someone.

Sometimes I can say, “Hello!” or “Hi!” It’s a great way to start a conversation and a good way to make new friends. I love to greet people because it makes me happy; it also makes the other people happy. They smile and respond to the greeting. I can also use sign language to greet someone!

When I see someone I do not know I could say “Nice to meet you.” or “Hello!” When I say hello to a new friend I will try and remember to ask them their names. I can also tell my new friend my name.

Sometimes I can shake their hands, or wave my hand to say hello. Sometimes I can just nod my head and say hi.

Saying hi to new friends is fun! People like me when I say hello.

Greeting can make people feel good.

References

1. Weiss, M., Harris, S.: Teaching social skills to people with autism. Behav. Modif. **25**, 785–802 (2001)
2. McConnell, S.: Interventions to facilitate social interaction for young children with autism: review of available research and recommendations for educational intervention and future research. J. Autism Dev. Disord. 351–373 (2002)
3. Cooper, M., Griffith, K., Filer, J.: School intervention for inclusion of students with and without disabilities. Focus Autism Other Dev. Disabil. **14**, 110–115 (1999)
4. Shipley-Benamou, R., Lutzker, J., Taubman, M.: Teaching daily living skills to children with autism through instructional video modeling. J. Positive Behav. Interv. **4**, 166–177 (2002)
5. Swaggart, B., Gagnon, E., Bock, S., Earles, T., Quinn, C., Myles, B., Simpson, R.: Using social stories to teach social and behavioral skills to children with autism. Focus Autism Other Dev. Disabil. **10**, 1–16 (1995)
6. Palmer-Ormsby, J.: Proposal project to improve greeting skills of an adult with disabilities using social stories. All Graduate Plan B and other Reports. Paper 54, (2011)
7. Azuma, R.: A survey of augmented reality. Presence: teleoperators Virtual Environ. **6**, 355–385 (1997)
8. Richard, E., Billaudeau, V., Richard, P., Gaudin, G.: Augmented reality for rehabilitation of cognitive disabled children: a preliminary study. In: Proceedings of Virtual Rehabilitation. 102–108 (2007)
9. Juan, M., Alcaniz, M., Monserrat, C., Botella, C., Banos, R., Guerrero, B.: Using augmented reality to treat phobias. IEEE Comput. Grap. Appl. **25**, 31–37 (2005)
10. Putnam, C., Chong, L.: Software and technologies designed for people with autism: what do users want?. In: Proceedings of the 10th international ACM SIGACCESS conference on Computers and accessibility, pp. 3–10. ACM (2008)
11. Bosseler, A., Massaro, D.: Development and evaluation of a computer-animated tutor for vocabulary and language learning in children with autism. J. Autism Dev. Disord. **33**, 653–672 (2003)
12. Parsons, S., Leonard, A., Mitchell, P.: Virtual environments for social skills training: comments from two adolescents with autistic spectrum disorder. Comput. Educ. **47**, 186–206 (2006)
13. Farr, W., Yuill, N., Hinske, S.: An augmented toy and social interaction in children with autism. Int. J. Arts Technol. **5**, 104 (2012)
14. Bai, Z., Blackwell, A., Coulouris, G.: Using augmented reality to elicit pretend play for children with autism. IEEE Trans. Vis. Comput. Graph. **21**, 598–610 (2015)
15. Escobedo, L., Nguyen, D., Boyd, L., Hirano, S., Rangel, A., Garcia-Rosas, D., Tentori, M., Hayes, G.: MOSOCO: a mobile assistive tool to support children with autism practicing social skills in real-life situations. In: Proceedings of the SIGCHI Conference on Human Factors in Computing Systems, pp. 2589–2598. ACM (2012)

16. Alessandrini, A., Cappelletti, A., Zancanaro, M.: Audio-augmented paper for the therapy of low-functioning autism children. In: CHI '13 Extended Abstracts on Human Factors in Computing Systems, pp. 505–510., Paris, France (2013)
17. Engage| Project Autism, http://projectautism.org/engage
18. Home Page, http://www.speakingofspeech.com/Home_Page.html
19. Gray, C.: The new social story book. Future Horizons, Arlington, Tex (2010)
20. Chen, C., Lee, I., Lin, L.: Augmented reality-based self-facial modeling to promote the emotional expression and social skills of adolescents with autism spectrum disorders. Res. Dev. Disabil. **36**, 396–403 (2015)

The App Game Interface Design for Frozen Shoulder Rehabilitation

Chia-En Chung and Chien-Hsu Chen

Abstract This paper aims to develop an appropriate game interface design for frozen shoulder rehabilitation. The main treatment of frozen shoulder involves diagnose of doctor and proper rehabilitative exercise to break up adhesion and improve the joint mobility and functions. It leads to a problem that whether to do the exercise after the treatments of doctor is all depends on the patient's motivation and often not execute. To address this, we construct an app game design which can be easily used by mobile platforms in order to enhance the motivations of patients to keep doing regular rehabilitation at home and the results can be uploaded into server for screening by doctor. The prototyping of this game design are conducted and several users are invited into the evaluation process to revise the game design.

Keywords Frozen shoulder · Game design · Interface design

1 Introduction

Frozen shoulder is an extremely painful and debilitating condition leading to stiffness and disability [1]. It is a slow onset of pain felt near the insertion of the deltoid muscle and make the patients enable to sleep on the affected side with restriction in both active and passive elevation and external rotation, yet with normal radiographic appearance [2]. There are three frozen shoulder severity stages are categorized. In stage one, it last two to nine months and with progressive stiffening and increasing pain on movement. Stage two last four to twelve months,

C.-E. Chung (✉) · C.-H. Chen
Department of Industrial Design, National Cheng Kung University, No.1 University Road, Tainan, Taiwan
e-mail: chiaen9@gmail.com

C.-H. Chen
e-mail: chenhsu@mail.ncku.edu.tw

M. Soares et al. (eds.), *Advances in Ergonomics Modeling, Usability & Special Populations*, Advances in Intelligent Systems and Computing 486,
DOI 10.1007/978-3-319-41685-4_45

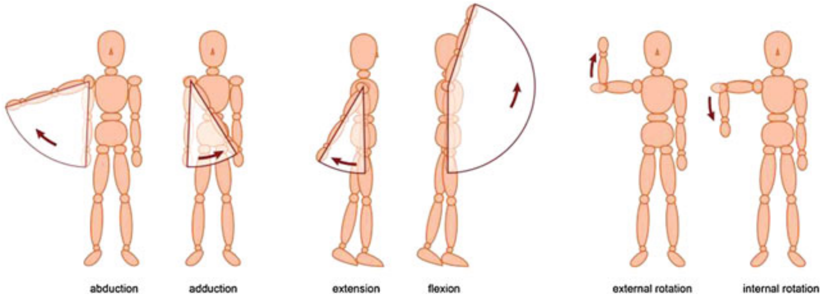


Fig. 1 The six directions shoulder joint can rotate

there is gradual reduction of pain but stiffness persists with considerable restriction in range of motion. While in stage three, there is improvement in range of motion with resolutions of stiffness. Besides the status of every stages above, there may have some differences between every patient's situations according to our observation and doctor visiting.

There are six directions (flexion, extension, adduction, abduction, medial rotation and lateral rotation) that shoulder joint can rotate (Fig. 1). Frozen shoulder or adhesive capsulitis is a disorder that is featured by a movement pattern of limited external rotation, internal rotation, abduction, and flexion [3].

It is commonly prescribed a six to twelve week course of physiotherapy. The whole physiotherapy process may involve passive mobilization and capsular stretching, it usually involve heating tissues as adjuncts before the physiotherapy every time [1]. Because of the limitation of medical resources, doctors usually prescribe home exercise programs such as towel stretch exercise for shoulder internal and external rotation and wall climb exercise by fingers for shoulder flexion and abduction. While doing towel stretch, it might cause secondary injury if hands slip off due to lack of safety assist device while using towel stretch exercise. In this home exercise program, doctors usually have to spend time explaining and correct patients' postures and the accuracy and frequency of home-based rehabilitation can merely relied on patients' statement, instead of data analyzed objectively and concretely [4]. A critical component in most of motor rehabilitation is task repetition, and it can rapidly lead to boredom and noncompliance with treat protocols [5]. As a result, rehabilitation progress of patient is slow and unsteady [4].

To improve the current situation, we designed a system that combines wearable devices and a mobile app game. The main purpose of this study is to design an app game interface that helps patients pay attention to the games and ignore the tedious training repetitions and pain during rehabilitative exercises.

2 Related Work

There is a research that patients complete standard rehabilitation tasks by interacting with virtual reality (VR) game exercises [6]. However, it needs a Kinect, a projector, an inertial tracker and a repository to conduct the rehabilitation. The initial devices makes it difficult to implement. There are also some researches that use app games to help rehabilitation smoothly such as ARMStrokes—a mobile app for everyday stroke rehabilitation [7], MyWalk—a mobile app for gait asymmetry rehabilitation [8]. Furthermore, smartphones can be easily carried to any place and do not require complicated installation or configuration processes. We think it would be a more appropriate device. To detect the patients' moving angles accurately, we provides an app game integrate with wearable devices system for frozen shoulder rehabilitation.

We reorganized other studies and figure out some instructions for our rehabilitation game system:

(1) The game mechanics must be formed by appropriate therapy behavior.
(2) There are wide range of abilities with users, it is essential to have flexibility to individualize.
(3) Social interaction can encourage people playing games.
(4) The game should form powerful therapeutic relationship with therapist in order to allow intuitive judgments over whether progress is being achieved.
(5) Make up the deficiency of visit incapability and provide supports frequently [9, 10].

Then we incorporate the instructions in our design to make out the app rehabilitation game interface.

It is important for the developers and designers to take into account the user's needs and expectations while developing rehabilitation games that really do enhance engagement and increase motivation. To maintain therapeutic principles in game designs is essential. It also appeared that the chances of users experiencing technology failure is increased if the system lacks clear instructions or the users are unable to fully understand the games [4]. A research had presented a virtual reality games for movement rehabilitation in neurological conditions. It shows that virtual tutor design makes patients quickly examine themselves to determine whether they're following the video guidance correctly. Reported by users in other studies, the game were found to be enjoyable if the intervention was easy to learn and to play [4].

3 Methodology

There are two part in this rehabilitation system design. One is the design of the shoulder and wrist wearable devices with sensors in them to detect the movement. The other is the app game interface design. In this study, we focus on the design of an app game interface for frozen shoulder rehabilitation.

3.1 User Study

We have interviewed three patients, three middle-aged people who are not with frozen shoulder, two therapists and one doctor in this research.

Observation. We observed therapy process of patients for about two months and interviewed therapists and doctor. It makes us understand the frozen shoulder treatment more clearly.

Interview. To understand our target user group clearly, we have elaborate a questionnaire to help us interview them. After the interview, we find out our users usually play the app games that are simple or classic such as Candy Crush, block game. This discovery will be one of our consideration.

In the interview of patients and people without frozen shoulder, we discovered that people in this age usually use app game that (1) with simple and can be used easily menu interface with gorgeous playing interface, (2) is usually not a competitive game, (3) with familiar playing rules, (4) simple plot. In our design, we try to merge this four features in our game and interface design to make it attractive.

We adopted activity theories [11] to analyze the details of frozen shoulder rehabilitation game exercise activity and identified the patients' context and activity in the rehabilitation process to design the activity properly in our system (Fig. 2).

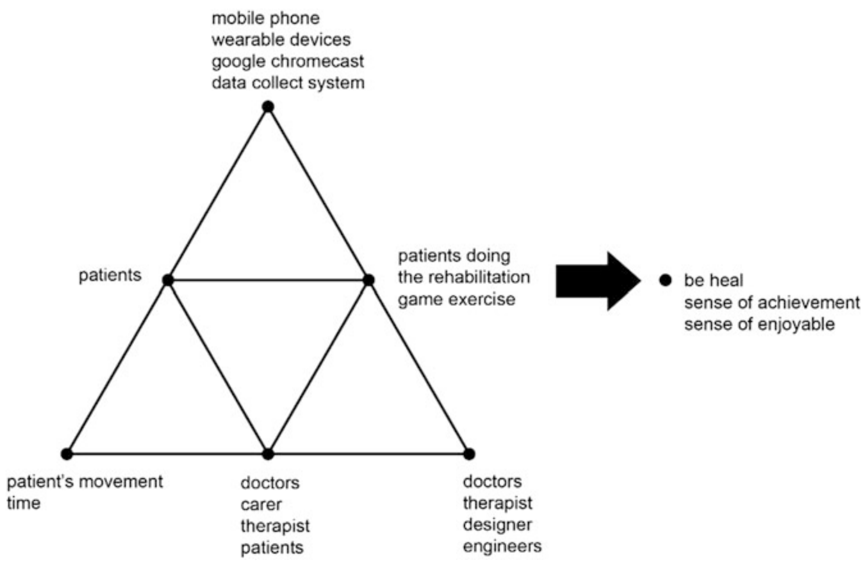


Fig. 2 Activity structure for frozen shoulder rehabilitation app game design

3.2 Game and Interface Design

We set up a group of expert in different background to do brainstorming and create three concepts. After two workshops of mockup testing and questionnaire interviews, we have decided our concept. Figure 3 is our app interface process. Patients can put on the wearable devices and use Google Chromecast which can produce their mobile screens on bigger screen to carry on the rehabilitation. The game interface process we designed include a log in page to record individual rehabilitation data, a personal page to provide social interaction and display current status, wearing devices tutorials to provide tutor, heat therapy reminding, posture correction pages, game playing interfaces and achievement page to present this time achievement.

We adopt the following normal ranges of movement of shoulder joint: flexion, extension, adduction, abduction, internal rotation and external rotation in our design. In this game, patients can control a virtual object according to their shoulder joint mobility and the maximum ranges of movement of patients' shoulder joint is used to determine the difficulty levels of the game. The patient can reach next level of game which means the patient's shoulder joint is going to reach a bigger range of movement. Patients play the game to carry out the rehabilitative exercises correctly through the correction and measurement of present shoulder joint mobility. It also could record and display the patient's progress to increase the sense of accomplishment and provide feedback of achievement.

Therapists and doctor have suggested that it would be better if the shoulder have the chance to exercise in every direction. According to the moving direction of the six movement, we separate them into three groups: abduction and adduction (AA), internal rotation and external rotation (IE), flexion and extension (FE). Furthermore,

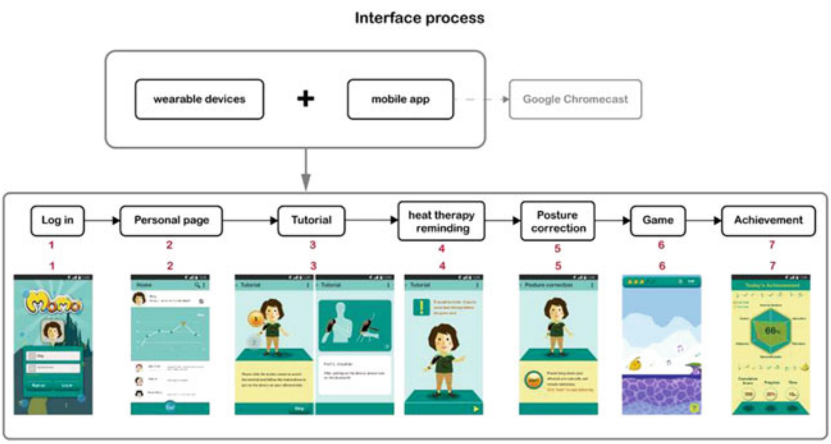


Fig. 3 Devices and app interface process

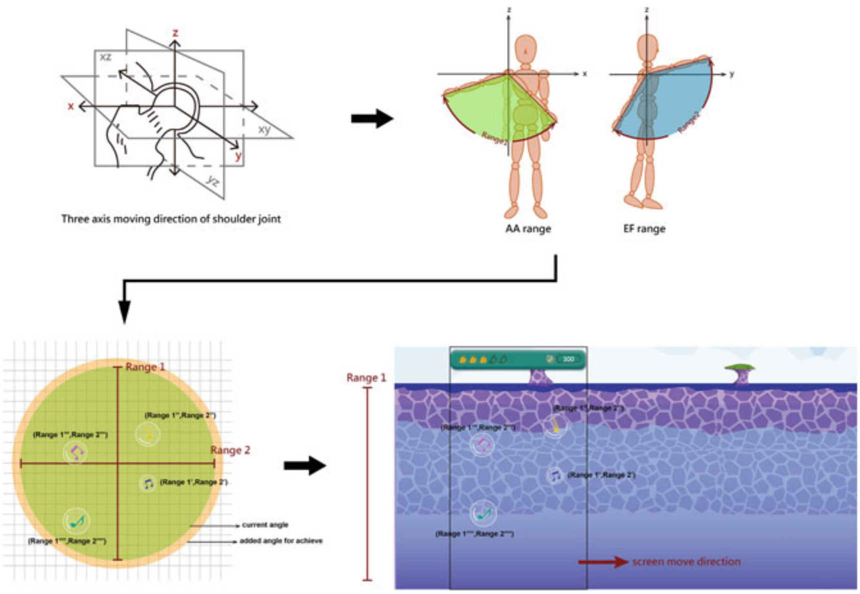


Fig. 4 Mapping the angles range of shoulder mobilization to the game interface

we defined the six directions on xyz axis (Fig. 4) which constitute three surfaces to map on the interface design.

We find out that AA and FE can present the large pattern of motion on xz and yz surface. To increase the fascination, the AA and FE were merged in one of the playing interface. We use AA range as horizontal axis and FE range as vertical axis to define the bubbles range of positions (range1’, range2’). The doctors also suggested to add about 5° as the range for the game, it can help patients progress.

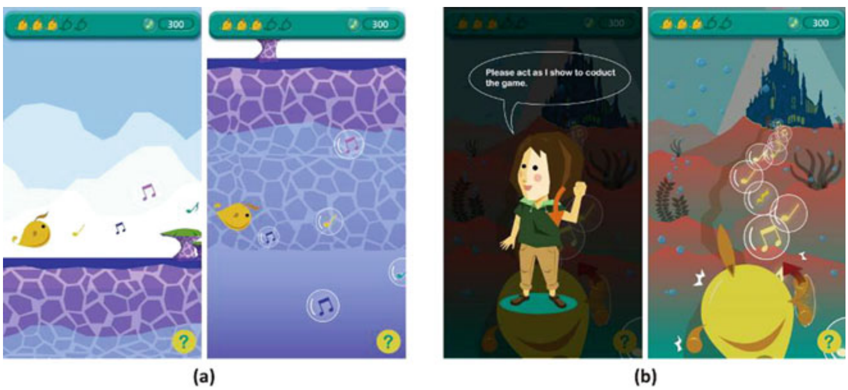


Fig. 5 **a** Game interface of AA, FE. **b** Game interface of IE and ER with tutorial

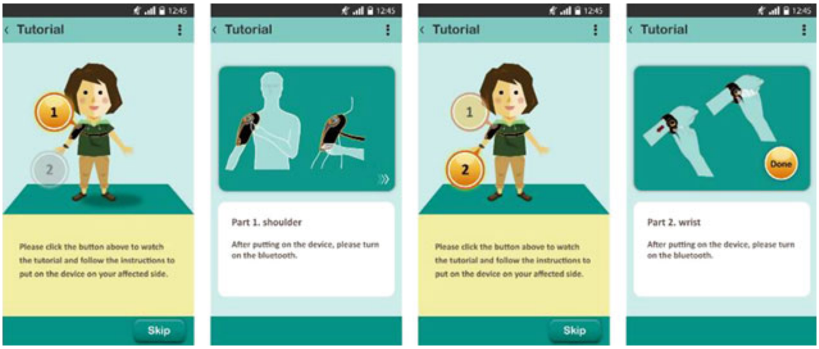


Fig. 6 Wearable devices tutorial interface

Patients can control a character by the shoulder movement of AA and FE to get bubbles (scores). The other playing interface is designed for IE which present large pattern of motion on yx surface. Because IE is more difficult to present and image on the interface, a tutorial of teaching user how to move will appear before the game start. When in the game of IE, users can control the character move forward or retreat by internal rotation or external rotation to get bubbles (Fig. 5).

To wear the wearable devices correctly is important in this rehabilitation game, there are sensors that detect the users shoulder joint angles. To insure whether the user wear the devices correctly, we present the tutorial step by step interface in the process (Fig. 6).

Since each case is unique, one fixed rehabilitation approach will not be able to support a broad range of those recovering from frozen shoulder. Therefore, the app was designed to be easily customizable for the special needs of a specific person. This game set up an angle measurement interface (Fig. 7) to collect the data of shoulder mobility angles (AA, IE, FE). The designed angle measurement interface

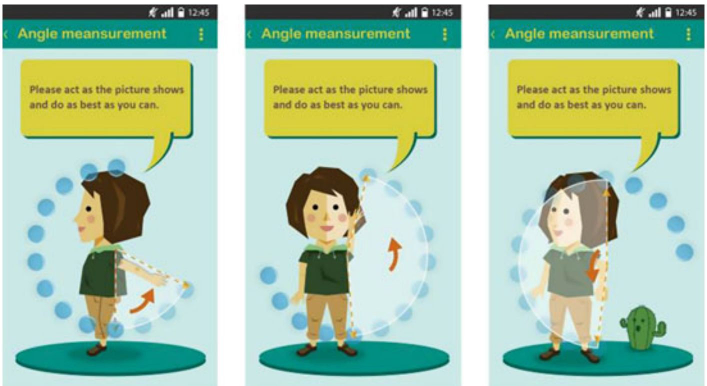


Fig. 7 The measurements of patients' present angle interface

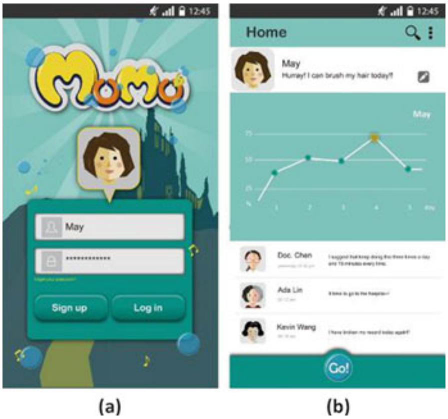


Fig. 8 **a** Sign up page. **b** Home page interface. Patients can see their personal statuses and leave or get messages on this page

is intended to make the boring and repeatedly task more interesting and fun. The system can collect the angle data from the reaching bubbles by the patients.

In the process, we also provide sign up page and personal home page (Fig. 8) for patients to check out their rehabilitation progress and leave messages to interact with others. The doctors also can give some suggestions about the patients' rehabilitation on this page.

To show the achievement can enhance user's sense of achieve (Fig. 9). We designed this page to give the patients some feedback about their rehabilitation. It can help patient understand their achievement and encourage them doing rehabilitation continually. We draw a hexagonal and equally distributed center to every angle into 10 to present the rehabilitation they do last time and this time. There also shows the progression rate which calculate by last time and this time achieving angles, cumulative score which cumulate from the past to the present and usage time for this time rehabilitation.

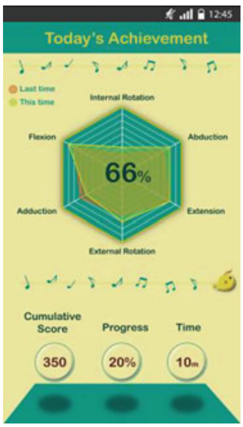


Fig. 9 Rehabilitation achievement page

While design the interface, we followed the Android mobile user guideline to make sure our design is appropriate and put a lot of thought into what would make our app the easiest and most practical to use.

3.3 Preliminary Evaluation

We prototype the interface on POP, and find 7 people which includes a graphic designer, a therapist, two of our target user and three designers to try out. There are some comments and suggestion they give after they try it. They think the instructions of the interface is clear and simple to follow, but it would be used smoothly if the buttons all on the same place. They also commented that the interface is fascinating. The interface was designed to include animation, but we only can present it as a pictures right now.

4 Conclusion

Though there are several other rehabilitation app games, we think our app game system is unique. This app game system is mainly to decrease medical cost for traditional frozen shoulder therapy, and make sure the patients can do the rehabilitation themselves at home correct and effective. To make the patients enjoying this app game system rehabilitation, the game interface design is important. It should not only ingratiate with therapeutic principles but also fascinating. When we designed this, we kept in mind through each step of our app's creation were functionality and fun. This app we originally design for people with frozen shoulder, and it is one of our goal of development that everyone can use it as an app for exercise. To accomplish this, we need to design our app as good as possible to cater everyone's need.

References

1. Guyver, P., Bruce, D., Rees, J.: Frozen shoulder—a stiff problem that requires a flexible approach. Maturitas **78**, 11–16 (2014)
2. Hand, C., Clipsham, K., Rees, J., Carr, A.: Long-term outcome of frozen shoulder. J. Shoulder Elbow Surg. **17**, 231–236 (2008)
3. Vermeulen, H.: Measurement of three dimensional shoulder movement patterns with an electromagnetic tracking device in patients with a frozen shoulder. Ann. Rheum. Dis. **61**, 115–120 (2002)
4. Tseng, K., Su, W., Hsu, C.: A tele-rehabilitation service mode for patients with adhesive capsulitis. Workshop on Interactive Systems in Healthcare (WISH) 2014 (2014)

5. Lewis, G., Rosie, J.: Virtual reality games for movement rehabilitation in neurological conditions: how do we meet the needs and expectations of the users? Disabil. Rehabil. **34**, 1880–1886 (2012)
6. Huang, M., Lee, S., Yeh, S., Chan, R., Rizzo, A., Xu, W., Han-Lin, W., Shan-Hui, L.: Intelligent frozen shoulder rehabilitation. IEEE Intell. Syst. **29**, 22–28 (2014)
7. Guo, J., Smith, T., Messing, D., Tang, Z., Lawson, S., Feng, J.: ARMStrokes: a mobile app for everyday stroke rehabilitation. In: Proceedings of the 17th International ACM SIGACCESS Conference on Computers and Accessibility, pp. 429–430 (2015)
8. How, T., Chee, J., Wan, E., Mihailidis, A.: MyWalk: a mobile app for gait asymmetry reha bilitation in the community. In: Proceedings of the 7th International Conference on Pervasive Computing Technologies for Healthcare, pp. 73–76. ICST (Institute for Computer Sciences, Social-Informatics and Telecommunications Engineering) (2013)
9. Kairy, D., Tousignant, M., Leclerc, N., Côté, A., Levasseur, M., Researchers, T.: The patient's perspective of in-home telerehabilitation physiotherapy services following total knee arthroplasty. Int. J. Environ. Res. Public Health **10**, 3998–4011 (2013)
10. Linehan, C., Waddington, J., Hodgson, T., Hicks, K., Banks, R.: Designing games for the rehabilitation of functional vision for children with cerebral visual impairment. In: Proceedings of the extended abstracts of the 32nd annual ACM conference on Human factors in computing systems, pp. 1207–1212. ACM (2014)
11. Uden, L.: Activity theory for designing mobile learning. IJMLO **1**, 81 (2007)

Usability Evaluation of Movement Support Service Robot for Elderly

Myung Kug Moon and Seon-Chil Kim

Abstract The purpose of the study is to develop quantitative usability Evaluation criteria of movement support service robot for elderly people. To develop the usability testing criteria of a movement support service robot for elderly people, this study carried out the followings: product selection, selection of target product, IRB passing, development of leading indicators, correction by experts, preliminary evaluation according to the scenario and development of core indicators. For this, a draft questionnaire was developed against the elderly at around age 60. After small group tests and interviews, the experts modified the initial draft to the Usability evaluation Criteria of movement support service robot for elderly people. Development indicators include 4 subscales—Safety, Controllability, Efficiency and Satisfaction. All of the 4 subscales of indicators were passed the reliability criteria by 4 groups of elderly people, divided by gender and the familiarity of smart move devices. Development indicators cover a wider area of user experiences of the movement support service robot and are a good measurement tool to help both the users and developers of the service robot for elderly people.

Keywords Usability test · Movement support service robot · Elderly

1 Introduction

South Korea is one of the countries with the fastest aging of population in the world. Entry into an aged society (14 % or more on the ratio of population ages 65 and over) is expected in 2018, and entry into a super-aged society (20 % or more on the ratio of population ages 65 and over) is expected in 2026.

Despite the situation, senior friendly product manufacturers in Korea are small businesses and they are in an environment difficult for an independent development of products to be responsive to consumer demand and promote vitalization of a

M.K. Moon (✉) · S.-C. Kim
Keimyung University, 1095, Dalgubeol-Daero, Daegu 42601, Korea
e-mail: mkjy2011@gmail.com

M. Soares et al. (eds.), *Advances in Ergonomics Modeling, Usability & Special Populations*, Advances in Intelligent Systems and Computing 486,
DOI 10.1007/978-3-319-41685-4_46

market. Furthermore, the most of products circulating in the market do not show any functional difference, and similar products are being supplied instead.

Accordingly, the government of South Korea is supporting R&D funds for research and development of assistive devices for elderly and disabled people to support vitalization of senior friendly industry, but it only supports localization of import-dependent core components or some items with insurance benefits.

Senior friendly products should be developed based on information on fundamental physical characteristics of senior citizens because they should be easy and safe to use for elderly people, however, the Korean industry is simply imitating the imported products because of the absence of ergonomic information on senior people.

Therefore, this is the time that a support policy is needed to lead development of the Korean industry through a response to demand of senior friendly industry, which is rapidly expanding in this aging society and a usability test and supply of senior friendly products which can be a foundation for healthy development of a market and competitiveness of technology and product of domestic industry.

In the past, government policies for aging populations simply focused on relief of inconvenience due to the deterioration of physical and mental functions; now, however, they are aimed at securing quality life even after their retirement as ordinary people. The most influential factor in the quality of life of elderly people seems to be the personality and emotion of the person among psychological factors. Furthermore, social networks based on age, religion, social gathering, marriage, and friends, etc., and level of participation in the networks have impact on the quality of their lives [1].

The active introduction of IT technologies is emerging as one of the ways to help overcome the physical, mental, and social limits of aging generations and assure the quality of their lives. The development of technologies in Korea for the last decade has enabled generally convenient human lives and quality spare time services without limits in time and space including management of personal connections, etc. [2].

Robots that perform diverse functions in the environment where they coexist with human beings have been developed and utilized by advanced IT and digital home technologies. In particular, robots in diverse shapes are being developed to provide better healthcare services such as walk training robot, move support robot, nursing robot, etc. [2].

In an effort to overcome physical limits, physical activity aid robots are being developed into movement support robots to which IT technologies are connected for location, navigation, object recognition, etc., to support the activities of the aged generation with poor mental judgment beyond the limits of motorized wheelchairs that are fully dependent on human for the operation of the machines. In Korea, too, the development of the robots is now in the beginning stage, and the establishment of criteria for the evaluation of their usability seems to be meaningful.

Thus, this study seeks to identify the criteria for the usability evaluation of movement support service robots wherein senior-friendly products and IT are combined so that they can serve as reference for the future development of related products.

2 Methods

2.1 Usability Test of Senior Friendly Products

Usability testing is a means to determine whether a given senior friendly product will meet its intended users' needs and preferences. By extension, it is a way to judge if a senior friendly products either resistant to or vulnerable to dangerous use errors that could lead to the user injury.

However, a usability test should be performed on senior friendly products from a different viewpoint with consideration that a range is particularly because elderly people are users and they have physical and psychological distinctiveness.

Various international standards are applied to the usability test, and recently, standards are actively established and revised. Regarding the international standards, ISO/IEC Guide 71 (2001) lists standards for the needs of elderly and disabled people, especially considerations for products, services, etc.

Also, ISO/TR 22411 (2011) proposes a universal design guide related to technical information and data design needed for senior citizen, and recently, guidelines for usability of medical devices are defined by IEC 60601-3 (2015), IEC 62366 (2007), etc.

In the United States, ANSI/AAMO HE74 (2001) defines a human factor designing process for medical devices, and AAMI HE75 (2009) descriptive information on testing and method of usability engineering in designing medical devices.

2.2 Concept of Movement Support Service Robots

Movement support service robots refer to robots that can support the physical, psychological, and cognitive functions of aged people and provide services for their daily lives. In particular, nursing facilities, silver towns, hospitals, etc., for the elderly people have become combined and larger by their more available financial resources, changes in family structure, and higher demands for welfare services; there is a need for the development of robots to support their motion or walking in wider indoor or outdoor spaces.

Many studies have been done on robots to assist the physical movement or motion of the elderly, health support robots through the measurement of their vital signs, or monitoring robots to detect their abnormal conditions. Nonetheless, more studies on robots that can support them—focusing on their emotion or feelings—should be done urgently considering their high demands, possibility of success in the market, and impact on the lives of the people.

Devices that are currently helping the walking or motion of the elderly are walking sticks, walkers, wheelchairs, etc., and developed countries such as the US, Japan, etc., are utilizing many resources for healthcare devices as further investment, etc. Note, however, that devices supporting the indoor or outdoor walking of aged people with poor muscular strength on their lower limbs or paralysis symptoms are now at the early stage of development, and preoccupation of related technologies or securing of dominant position is required.

The importance of developing items that can closely connect silver robots to our daily lives in a natural way is emerging, and fast development and commercialization in a shorter period are possible in the industry by combining with items developed by other related industries (U-health, contents, medical industries, etc.), not production of results from robot application or items developed by the existing motion robot technology or healthcare studies.

2.3 Procedure of Usability Test of Senior Friendly Products

A usability test of senior friendly products follows a process in Fig. 1. Once a request for a product is received, cases and data related to usability for each item are collected and usability test indicators for the relevant items and products are developed. Usability test indicators comply with ISO 20282-1 and they are composed of usability, user interface, ease of operation, effectiveness, efficiency, satisfaction, etc.

In general, a group of consumers using the products and experties participates in development of usability test indicators. However, in case of the products for elderly, seniors, care workers or caregivers who help with daily life of seniors, etc. participate in the usability test. They develop product specific usability test indicators through 4 or more meetings, etc.

Once the development of usability test indicators is completed, usability test is performed in sample population, and in general, subjective usability, biomechanical test, biophysical test, etc. is also evaluated (Table 1).

Fig. 1 Example of test use for usability test

Table 1 Procedure of usability test of senior friendly products

Senior-friendly products DB building		
Presentation on information sharing guideline to companies		
Usability evaluation indicator assessment	Sample group determination evaluation indicator repeated assessment and result production	Experts' Meeting
Usability evaluation indicator development	Item development by product Quantitative/qualitative evaluation indicator Correction or revision through preliminary test	
Home and overseas data collection/analysis	Usability evaluation case collection by product	
Senior-friendly company evaluation request	Product decision through public invitation of companies	

2.4 Usability Test of Senior Friendly Product

This study will examine a method of usability testing on senior friendly products and a product improvement application plan through the usability test on movement support robot.

Interview of the customer and the producer

Consumers were selected from among people aged around 65, who have used any of the smart devices, who expressed intention of voluntary participation in the interview, who have scored more than 23 points in MMSE (Mini-Mental State Examination: a simple Korean mental checkup kit), and who have used any of the IT devices such as smart phones or PC, etc.

Based on "Magic Number 5" of Nielsen and by additionally considering the following aspects, the proper number of interviewees for this study was calculated to be 20. According to studies on technologically intensive products or information technologies, the most influential factors in technology acceptance and use are gender and technical competence. In order to select user groups that can clearly represent users of hi-tech products as the target of this study, the gender of users and their technical competence, i.e., whether they are good or poor at using the technology, were considered, and they were divided by gender (female VS. male) and technical competence (competent VS. incompetent). Five interviewees were selected for each group, and they participated in the usability evaluation test.

Make a checklist of usability testing

1. Safety

Since the targets of movement support service robots are elderly people who have difficulty moving or whose response is slower than general people, the usability evaluation indicator that should be considered first is "safety."

Safety: Stable movements in diverse conditions are the most basic evaluation item since the products can move by themselves, they are used in diverse environments including indoor or outdoor, etc., and they can be too heavy for elderly people. Dangers of fall of the products or physical dangers to users in two situations —"stop" and "move"—were evaluated for the preliminary evaluation.

Contact danger: Considering the physical features of elderly people with high possibility of injury even with comparatively weak stimulation, the level of possible injury of users when the robots come in contact with the users was evaluated.

Others: "Moving speed" and "response level" to check whether aged people fully understand and they can respond when robots move and "electric shock danger" such as electrically motorized equipment were included in the evaluation.

2. Operation

Considering the behaviors or learning capacities of elderly people who are not accustomed to IT devices and features of the devices moving indoors and outdoors with users on them, direct and easy operation is essential so that they can respond to dangerous situations.

Driving: Movement support service robots are products that move to the destinations by themselves with users on them, and evaluation of their driving is indispensable. The level of accurate movements to targeted points was evaluated.

Brake: The level of operation of brake was evaluated to check whether users can stop the robot as soon as they want in order to respond to emergency or other situations while moving. Questions on the operation and clearance of brake were included.

3. Efficiency

Since movement support service robots are devices focused on movements, easy operation by anyone and simple operation through the provision of consistent and accurate information are important elements.

Easy Learning: Evaluation on how easily and quickly users can learn how to operate the robots to get to the points they want.

Accuracy: Evaluation on whether the users can get accurate information on POI (Point of Interest: information on a spot the user is interested in), search results, etc., while moving or stopping.

Accessibility: Evaluation on whether the users can use them instantly even without knowledge or past experience of IT devices.

Table 2 Characteristics of subject

	Elder (n = 20)	Helper (n = 20)
Sex	M 13/F 12	M 5/F 20
Age (year)	72.64	59.04
Height (cm)	161.80	159.64
Weight (kg)	66.32	60.24
MMSE-K	25.60	–
Career	–	6.48

Consistency: Evaluation on the provision of consistent interface to avoid confusion among users.

Visibility: Evaluation on how well users can recognize the information provided by the device during operation.

Elderly people ages 65 and over and care workers or caregivers with 3 or more years of experiences were selected as subjects for this study, and people who do not have problem in cognitive function were recruited for this test (Table 2).

Caregivers used the shower chair after being educated about method of use and cautions. If they gave a negative score, which is 2 points or less for a detailed question, a qualitative evaluation was performed by recording a reason for the negative score on an evaluation form. Also, a message to manufacturer were recorded during evaluation although positive answers were given.

3 Results and Conclusions

The average safety of the movement support service robots was 3.27; safety in stopping (3.30), contact danger (3.30), response level (3.15), electric shock danger (3.30), and safety in movement (3.35) were generally positive among all safety-related items. As for the ratio of negative answers to identify issues by detailed item, danger of contact was highest with 10 %; there were no negative answers for the rest of the items (Table 3, 4 and 5).

Table 3 Users' safety evaluation results for the movement support service robot usability evaluation

n = 20			
Evaluation Item	Average	Standard deviation	Negative answers (%)
Safety in stopping	3.30	0.47	0.0
Contact danger	3.30	0.66	10.0
Moving speed	3.20	0.41	0.0
Response level	3.15	0.37	0.0
Electric shock danger	3.30	0.47	0.0
Safety during moving	3.35	0.49	0.0
	3.27	0.48	1.7

Table 4 Operation

n = 20				
Items		Average	Standard deviation	Negative answers (%)
Power operation	Location of switch	2.15	0.99	65.0
	Operation of switch	2.75	0.72	40.0
		2.45	0.93	52.5
Screen change	Screen change switch location	3.20	0.52	5.0
	Screen change switch operation	2.35	0.49	65.0
		2.78	0.79	35.0
Recharging work	Installation work	2.90	0.55	20.0
	Recharging operation	3.05	0.51	10.0
		2.98	0.72	15.0
Contents composition	Easy search	3.24	0.62	10.0
				10.0
				10.0
				10.0
	Malfunction prevention	3.13	0.52	0.0
				15.0
	System response speed	3.30	0.57	5.0
		3.21	0.59	8.6
Driving	Direction change	3.25	0.64	10.0
Efficiency	Easy learning	2.65	0.67	45.0
	Accuracy	3.30	0.47	0.0
	Accessibility	3.10	0.64	5.0
	Consistency	3.25	0.64	10.0
	Visibility	3.25	0.55	5.0
	Briefness	3.40	0.50	0.0
		3.16	0.62	10.8
		3.06	0.68	17.0

The satisfaction-related items garnered relatively lower points with average evaluation score of 2.96 and 20.7 % negative answers. In particular, the question on the quality evaluation of services provided by the robots—"Provided services and physical values of purchase (prices) are the same"—received 75 % negative answers; thus suggesting the need for urgent improvement.

Table 5 Satisfaction

n = 20			
Items	Average	Standard deviation	Negative answers
Noise	3.50	0.76	5.0 %
Exterior design	2.90	0.79	25.0 %
Understanding of manual	3.15	0.49	5.0 %
Continuity of use	3.00	0.73	15.0 %
Recommendation of product	3.00	0.56	15.0 %
Quality evaluation of services[a]	2.58	1.01	5.0 %
			75.0 %
	2.96	0.83	20.7 %

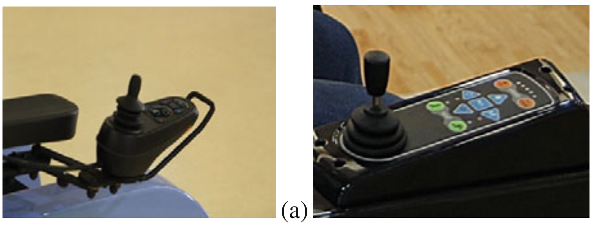
[a]See the Appendix for questions on the detailed items

3.1 Improvement Matters for Movement Support Service Robots (Example)

Operation Improvement

The power switch seems to be separated from other switches to avoid confusion among users during operation of the power switch. Moreover, a highly visible color (generally, red is most frequently used for the power switch) should be adopted so that aged users can find it easily and fast. In most cases, it is not easily found because there are no instructions on the switch; the font size of the switch should be more than 24 points in Gothic for easy reading of users (Fig. 2).

In reality, a certain proportion of aged or disabled users with low physical or mental capacities are excluded from the eligible users of the existing ICT products, which were made without considering the elderly people. Note, however, that this approach can mostly be improved through usability evaluation for the aged. Thus, more diverse policies are required to help the elderly enjoy the benefits of the IT society through the establishment of senior-friendly usability evaluation standards, active encouragement of development of ICT technologies considering the seniors, and maximum increase of usable target population of ICT products.



(a) (b)

Fig. 2 **a** Before; **b** After

References

1. Cutler, SJ.: Voluntary association participation and life satisfaction: a cautionary research note. J. Gerontol. **28**(1), 96–100 (1973)
2. Lee, E.: Service Robot for Home, IT Report, Korea Electronics Technology Institute (2004)

Framework Interface Components for Accessibility Issues in E-Commerce

Plinio Thomaz Aquino Junior and Marcelo Piazza

Abstract The accessibility support absence in the design of web sites is related to insufficient training of developers, project budget constraints, and the lack of techniques to support development activities that take into account accessibility. This paper presents a component framework developed from the viewpoint of accessibility, based on an interaction pattern language and on an accessibility guideline targeted to complete vision loss. An additional contribution is the development of a components development process that meets accessibility requirements, based on interaction patterns, using a process for the components specification and the usability engineering lifecycle elements.

Keywords Electronic commerce · Interface patterns · Software reuse · Component framework · Accessibility

1 Introduction

A significant number of business sites of the most profitable companies in the world are potentially inaccessible to people with disabilities [23], with only 4 % of e-commerce sites claim to have some compliance with accessibility practices [25]. The lack of accessibility is a barrier for people with specific needs, whether they are disabled or not [28]. As an example, using the Brazilian scenario, characterized as a developing country (or Newly Industrialized Countries), approximately 14.5 % of

P.T.A. Junior (✉)
Computer Science Departament, Centro Universitário Da FEI – Fundação Educacional Inaciana Pe. Saboia de Medeiros, Av. Humberto de A. C. Branco, 3972 S. Bernardo do Campo, São Paulo, Brazil
e-mail: plinio.aquino@fei.edu.br

P.T.A. Junior · M. Piazza
PT – Instituto de Pesquisas Tecnológicas, Av. Prof. Almeida Prado 532, Butantã, São Paulo São Paulo, Brazil
e-mail: marcelo@aquinus.com.br

M. Soares et al. (eds.), *Advances in Ergonomics Modeling, Usability & Special Populations*, Advances in Intelligent Systems and Computing 486,
DOI 10.1007/978-3-319-41685-4_47

the population have one or more types of disability [18] and 7.4 % of the population is elderly [19]. In this scenario becomes clear the social exclusion resulting from lack of sites that support digital accessibility. Even as a social obstacle, disability is no impediment to become the person an active participant in society. The works of examples as Aleijadinho, Louis Braille, Helen Keller, Ludwig Van Beethoven, Andrea Bocelli, John Forbes Nash Jr. and Stephen William Hawking corroborate this idea [11, 12]. The development of web applications not yet fully woken up to the issue of accessibility, even with the existence of laws that promote equal access to information [4, 35] and recommendations directed to the project concerned sites with accessibility [3, 5, 41]. The number of web projects that support accessibility [14] is very small. Several causes are cited as possible for this lack of support, such as difficulty in the interpretation of recommendations, inadequate training, insufficient time to incorporate accessibility, technical difficulties, inexperience, incompatible standards with speed change, financial factors, legal issues [23], developers, without the knowledge of techniques and organizations that do not apply them correctly [14], and the lack of techniques to support the project navigation and survey requirements focused on accessibility [15]. Apparently oblivious to the issues related to building accessibility to concerned sites, developers have sought the benefits of software reuse of design elements, such increased reliability, reduced risk in the process, a more efficient use of experts, adherence to patterns and greater agility in development [29]. The artifacts that promote software reuse are: **Frameworks**: simplified and reusable architecture that provides structure and generic behavior for a family of software abstractions [2]; **Components**: independent unit of software that has well-defined interfaces and dependencies that can be composed and deployed independently [33]; **Patterns**: known solution used for a recurring problem described minimally in the form of a problem, given a context and a tested solution [1, 10]. The production of reusable artifacts that incorporate accessibility guidelines can be a step towards minimizing the lack of support in the development of applications intended for use by people with disabilities.

The objective of this work is to produce a framework of components of the graphical user interface in the field of e-commerce considering shopping on the Web. It presents the minimum steps to make a purchase on the Web, developed based on an interface pattern language and based on a set of accessibility guidelines. It is expected to get a minimum compliance level in compliance with the relevant accessibility requirements to complete loss of vision through an evaluation. The choice of a specific deficiency to be addressed in this work admittedly has the limitation of not contemplate universal access. This allows authors to concentrate your time in looking for alternatives to mitigate the problems caused by inadequate project websites for the people he believes to be the most affected. However, it is expected that the process developed in this project can be applied to the service of universal access, provided they fulfill the requirements linked to other types of needs and support the assessment of people with other types of disabilities. To fulfill the objective of this work, a process that captures requirements from a standard e-commerce interaction while that record the techniques of accessibility recommendations that are verified by a test script was developed. Once the development of the framework, a sample application was built with the components obtained, which underwent an accessibility evaluation and this evaluation determines whether the proposed objective was achieved through the degree of attendance of the selected requirements.

2 Accessibility

Accessibility is defined as a way to provide access for people with a disability in degree of severity [39]. However, the accessibility features in the systems can aid the use of people who have physical disabilities, such as people with low literacy or who do not have inclusion with technology. The United Nations (UN) defines persons with disabilities as those who have long-term long-term physical, mental, intellectual or sensory impairments which in interaction with various barriers may hinder their full and effective participation in society on an equal condition with others [36]. The World Health Organization (WHO) defines how digital accessibility ease of use of information and communication technologies for people with disabilities [41]. In the literature are presented the terms disabilities and impairments, often simply translated by deficiencies. Despite bringing a more precise idea of what you want to set the lifting job requirements is not affected by this classification.

According to the World Bank [40], there are about 50 million people with disabilities in Latin America and the Caribbean, or approximately 10 % of the local population, although the collection methods vary from region to region. It is estimated that in Brazil [18], 14.5 % of the population has one or more types of disability, which corresponds to 24 million. The most common type of disability is related to difficulty or inability to see (over 16 million), followed by the difficulty or inability to walk (almost 8 million people) and the difficulty or hearing disability (more than 5 million of people).

3 Legislation and Recommendations

The Convention on the Rights of Persons with Disabilities [36] the United Nations highlights the social and economic importance of full participation of persons with disabilities, although there are still barriers that hinder their participation as equal members of society.

Signatories to the Convention on the Rights of Persons with Disabilities [36], undertake to develop, promulgate and monitor the implementation of minimum standards and guidelines for the accessibility of facilities and services open to the public or public use. Therefore, some countries have adopted specific regulations for the treatment of people with disabilities, such as: rehabilitation law in the United

States [35] law of disability discrimination in the United Kingdom [34] and Decree 5.296 in Brazil [4] to establish standards for the implementation of accessibility. For the implementation of rules or laws specific accessibility requirements are defined. These laws are the basis for the development of guidelines, recommendations and Accessibility systems. WCAG 2.0 [42] recommendations are directed to the construction sites that use the accessibility requirements and are not limited to a single specific need and not to a specific application domain.

In addition to the recommendations, the W3C also has a conformity assessment method for accessibility [38], composed of the following: (a) determine the scope of the assessment: determine the level of compliance is sought with WCAG, select representative samples pages for manual evaluation and identify all pages that will be evaluated; (b) Use accessibility evaluation tools for web: validate the markup language throughout the site and use at least two accessibility evaluation tools in selected samples; (c) manually evaluate representative samples pages: apply checklist of accessibility to the sample pages, examine the pages in GUI browser with the user; and (d) Summarize and report occurrences: summarize all the problems encountered and best practices identified for each page.

The level of service priorities is divided, according to the impact on accessibility, in [41]: Priority 1: needs to be satisfied or access to information in this document will be impossible for one or more groups; Priority 2: should be satisfied or one or more groups will find it difficult to access the information in this document; Priority 3: can be satisfied or one or more groups will find some difficulty to access the information in this document.

The compliance level with the WCAG recommendations ranges from A to Triple-A, and represent the level of service accessibility priorities. In Brazil, in order to meet a requirement of Decree 5296 [4] was developed Electronic Government Accessibility Model 3.0 (E-MAG) [3], which is restricted to national e-government sites. As the accessibility model, the E-MAG relied on WCAG 2.0 and despite using the WCAG as a reference, the e-MAG 3.0 was developed and designed for local needs, aiming to allow Brazilian priorities and keeping agreement with the trends of the area [3]. Unlike WCAG 2.0, the E-MAG 3.0 does not establish priority levels. Instead, the model relates a set of recommendations that should be obeyed in full. For each E-MAG recommendation 3.0 there are references to WCAG 2.0 success criteria and their corresponding techniques. At the end of accessibility model document there is a reference to the accessibility checklist [17], which was produced from Sonza research work [30] and is used in the site analysis. The contents of this checklist are grouped into: (a) Accessibility: readability with screen reader; (b) Usability accessibility: productivity, use efficiency and environmental functionality; and (c) Communicability accessibility: communication process that verifies that the user has understood the interface events and the information was transmitted clearly.

4 Frameworks and Components

Framework is a structure for supporting or enclosing something else, especially a skeletal support used as the basis for something being constructed. It's an external work platform or a fundamental structure. It's a framework that can be extended by instantiating specific plug-ins, also known as hot-spots [26, 32]. According Riehle [27], a framework is a reusable design accompanied by an implementation, and the project represents an application domain and implementation defines how this model can be implemented, even partially.

A framework differs from a conventional application by containing flexible points with different implementations for each instance of the framework, which are kept incomplete until the time of instantiation. In the development process of an application that uses a framework there is a stage called instantiation, in which hot spots are supplemented by the specific behavior of the instances [13]. The documentation of a framework can occur through standards [2, 21] that, although it contains the necessary elements for their understanding by a software developer, you may need to be more expressive than the context-problem-solution triad, commonly present in pattern languages, depending on the audience wants to serve.

The framework documentation should consider the audience for which it is intended [6], and provide means for an understanding of the domain is included, list of features included in order to encourage the reuse and reduce the learning curve. The framework documents may be intended to the application developer, the maintainer of the framework, the developer of another framework or for the verification team. A software component is an independent unit, and has well-defined interfaces and dependencies that can be composed and deployed independently. The component-based design addresses issues related to supply, develop and integrate components to improve the reuse [32].

According Szyperski [31], a software component is an independent unit of composition with contractually specified interfaces and explicit context dependencies, which can be deployed independently and can be composed of external teams. In this context, interfaces are contracts between different components.

For D'Souza [9], a framework is collaboration components where the components are specified with model types, some of which come with their own implementation. To use this framework is necessary to connect the components that meet the specifications. According to Szyperski [31], a framework of components is a software entity that serves the development of components in compliance with certain standards, and allows instances of these components are connected to the framework.

The framework produced in this work contains features specifically applied to e-commerce domain and consists of components of the graphical interface, so combining scaffolds features applications with domain framework features. As for the scope, being aimed at a specific area, it is a framework of enterprise applications, however is to focus the production of interface components (@HCI). The components of this work are extended by creating classes that implement abstract classes in the framework, classified as white-box. The components description of this work is based on the artifacts produced in the identifying components process of Cheesman and Daniels [7]: requirements, specification and composition, in addition to considering use cases, class diagrams, sequence diagrams, and component diagrams. Because they are components of the graphical user interface, the description is completed in a style guide to help the designer and to guide the developer.

5 Preparation Process of Framework

The scope of work is limited to van Welie Interaction Patterns [37] for e-commerce. E-commerce patterns in use are referred to by patterns e-commerce website. The control set the graphical user interface corresponds to the HTML 5, described by the W3C [38]. The control set in use is limited to the scope defined above. The accessibility recommendations selected consider the complete loss of vision and are contained in WCAG 2.0-W3C [38, 41]. These are used only recommendations for the interface control sets contained in components developed in this research. E-commerce patterns, HTML controls set and WCAG 2.0 recommendations are represented in Fig. 1 by inputs I1, I2 and I3, respectively. The components developed in this work are contained in a framework and belong to the graphical user interface, represented by A5 artifact. Each interaction pattern corresponds to a component. For a component to be prepared for each pattern is writing a use case and a domain model, represented by artifacts A1 and A2 respectively. The domain model and use cases are obtained through substantive identification technique and

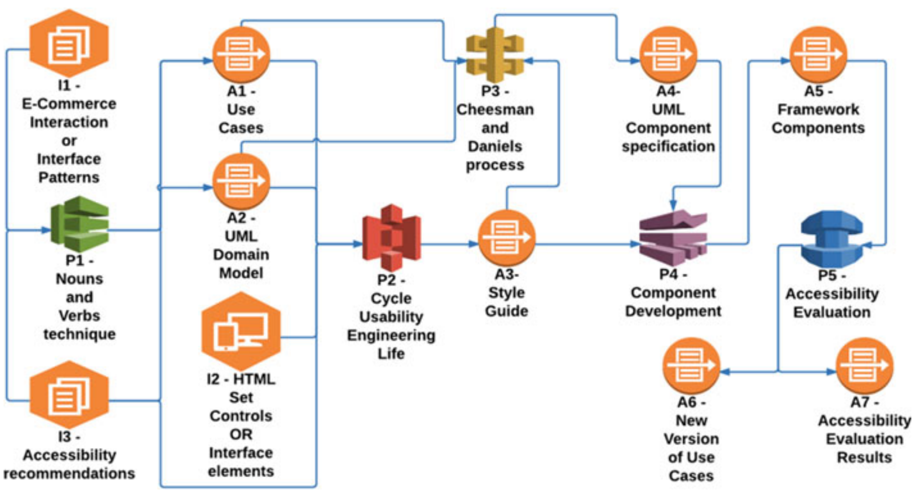


Fig. 1 Component development process that supports accessibility

verbs applied to each pattern, represented in Fig. 1 by P1 process. A guide styles is developed through the Usability Engineering Lifecycle by Mayhew [24], based on: (a) in the user profile set to work (total visual impairment or total blindness); (b) the selected patterns; (c) in developing Use Cases; (d) the set of graphical user interface controls for the web platform; and (e) in WCAG 2.0 recommendations. The life cycle is represented by P2 process, while the guide styles is represented by device A3, both contained in Fig. 1. The Domain Model, Use Cases and Style Guide are translated into Component Specifications through Cheesman and Daniels process [7]. The specifications are represented by A4 device, while the processing component is represented by the process P3, both contained in Fig. 1. The component is created based on your specification in conjunction with the style guide. The development component is represented by the process P4, and developed artifact component is represented by A5. After component construction, carried out the evaluation of accessibility of the W3C [38], represented by the P5 process, and the results are recorded in the Use Cases according to conformance levels achieved and the accessibility evaluation report. Altered use cases are represented in Fig. 1 by the device A6 and the accessibility evaluation report by the A7 artifact in the same figure.

Production of Use Case and Domain Model: The Nouns and Verbs technique is used for the production of Use Cases and Domain Model. However, the development of use cases and domain model is not part of a Declaration problem, but rather the interaction pattern.

Production of Style Guide: The Style Guide has been created based on the analysis of requirements Usability Engineering Lifecycle [24]: (A) Most of the Style Guide is developed from pre-existing inputs: van Welie Interaction Patterns [37], HTML 5—Controls Set [42] and accessibility guidelines WCAG 2.0 [41]; (B) The User Profile is developed using the existing **information** in the Use Cases of the Web applications by people with disabilities, the W3C [38]; (C) The Task Context corresponds to the Interaction Patterns [37] for e-commerce; (D) Usability Goals are replaced by Accessibility Goals; (E) The control set comprises those used by the patterns, and are identified after the development of the prototype; (F) A table with the control set is adapted to reference the process, its interface controls and the accessibility requirements that the project should include.

Production of Component Specification: The production of components specification was performed according to the process of Cheesman and Daniels [7]: (A) Unlike the purpose declared in [7], the process of component specification is applied for interface components with the user; (B) The domain is established by the interaction patterns [37] for e-commerce; (C) The Conceptual Business Model is elaborated based on Domain Model; (D) The Nouns and Verbs list was used for the preparation of model types and to identify business operations; (E) The specification of the Business Rules does not apply to the components, since the final product of work is a framework component, and therefore the business rules are contained in the application; (F) The component specification is refined based on the Style Guide. The refinement takes place by completing the details of the attributes, types, model constraints and adding operations signature details.

Evaluation Rules and Component Rating: The framework is evaluated under the accessibility aspects, respecting the evaluation rules to complete loss of vision. For the evaluation result documentation, each component use case document receives a section called **Special** Requirements. In this section, there is a table with the accessibility requirements and two columns where the accessibility evaluations results are documented. A sample application is developed and each component is placed on a page alone. Each component produced is inserted into an HTML page and goes through three evaluations: (A) a set of automated evaluation tools; (B) the designer of the framework; (C) for persons with complete loss of vision. The Special Requirements section is filled with the results of two evaluations (can be adapted for more evaluation results). The evaluation of the disabled person is registered in a specific document. At the end of testing, the accessibility report is populated with the evaluation result.

6 Component Framework Application

This is the framework preparation process involving the specification, development and testing of artifacts. Patterns are selected for the specification of the artifacts. Also selected are the accessibility requirements and set of HTML controls that are used in the application. This stage is produced Nouns and Verbs list by component containing the Nouns and Verbs list resulting from technical application to the selected standards. Afterwards it is made a list of techniques that validate the relevant accessibility requirements for this project.

Use Cases are designed using the standards, Nouns and Verbs List and the Recommendations List. To fill the Use Case, the information contained in the pattern are read a **first** time. The template Use Case is populated with the Primary Actor and Goal Use Case. The main flow of events is recorded in the Use Case. The Nouns and Verbs list corresponding to the pattern is confronted with the Use Case. The Nouns and Verbs List serves as a support for the verification of the main flow.

A second pattern reading is performed to identify alternative flows, and these are written in the use case. Again, Nouns and Verbs list is used as a support tool. After filling the alternative flows, add the recommendations list in the Special Requirements section of the use case. This procedure is repeated for each pattern. Using Nouns and Verbs list is drawn up the Domain Model or Business Model Concept.

At this time, the designers have patterns, accessibility guidelines, the set of control and the use cases, it uses the usability engineering life cycle to produce a style guide. The first step is to develop prototypes in HTML from the selected interaction patterns. After developing the prototype, begins completing the Style Guide based on the selected Interaction Patterns in prototypes, in the use cases and the set of HTML controls. After filling the Style Guide are added three items: (a) Controls Set x Accessibility Success Criteria; (b) Style Sheet Cascading Components; and (c) Resource Files. Filling controls Set and Accessibility Success

Criteria should consider the HTML controls contained in prototypes and selected Accessibility Criteria List. For each component are identified its controls and success criteria that should be considered in the project, and this information is filled in the style guide.

For each control and for each group of HTML controls (div, span and fieldset), a name is set to be referenced from the style sheets, and this information is filled in the style guide. For each literal text that is displayed for control, a name is set to be referenced from the component of the resource file, and this information is filled in the style guide. Having the use cases, style guide, of Nouns and Verbs list and conceptual model, the components are specified. Classes, interfaces and operations are recorded.

Once the specification of the components can be developed. To have the specification of components, abstract classes and interfaces are encoded. The implementation of the proposed framework produces a lot of artifacts, such as: Nouns List and Verbs for components, List of Selected Techniques, Standards List, Use Cases, Style Guide, Components Specification, testing instruments with users (e.g. invitation to participate in accessibility testing, presentation test and Design, Informed Consent and Informed, User Profile characterization Questionnaire accessibility assessment Questionnaire aided by people via Tools test results, test results with the help of people and result Accessibility Evaluation). All this content is available on the link (www.fei.edu.br/~plinio.aquino/frameworkaccessibility/), as well as the results of the participation of 7 people with total visual impairment.

7 Discussions and Contributions

Unlike the papers studied in reuse research area of software artifacts (which address the development of patterns for document framework or the development of frameworks based on design patterns and domain analysis) this work developed a Component Framework with based on interaction patterns. Additionally, the use case templates produced in this work compared to papers surveyed [8, 16, 20, 22] have the distinction of adding elements that explain the compliance with accessibility requirements can be faced with the recommendations for accessibility [41].

Considering the applicability, this work benefits the companies engaged in software development for e-commerce, because of the reuse promoted by the framework produced. With the difficulty in locating frameworks that simultaneously address e-commerce and accessibility, the software developer now has a mechanism that can bring efficiency in developing the application and that, because of the conformity assessment for accessibility which is submitted [38] also serves people with special needs. It also benefits companies that use e-commerce as a sales channel for providing an instrument previously undergone an accessibility evaluation, which helps the adoption of application building practices considering accessibility. By using the framework produced in this work, which has previously evaluated components according to recommendations for accessibility, the company meets the specific requirements set that will be met in the development of e-commerce site and the type of customer who might consider target audience.

The scenario chosen favors people who have complete loss of vision, because the use of the framework produced in this work, use e-commerce sites developed adequately to their needs. People who have some kind of special needs are often forgotten by developers of web applications [23, 25, 28], and meeting accessibility requirements becomes a means of promoting social inclusion.

Production of the framework under the aspects of accessibility confirms at least one of the hypotheses of work motivation: the development of an e-commerce site considering accessibility involves a longer work by the designer and developer of a site developed in same context, but without the need to meet these requirements. In a project from the perspective of accessibility, there are steps that explain this additional time consumption: (A) Accessibility guidelines add design requirements. The developer should be aware of these requirements and to put them into practice sometimes given to subjective criteria; (B) The developer should test the software after construction. Should successive times using different test tools because to specialize the tools will not be able to identify all accessibility issues. The developer should review the results because the tools also point to fault situations that are not wrong. After this verification cycle, the developer may be required to make corrections and re-checks; (C) After automatic verification and developer manual check, you must submit the application to check for people with disabilities. The tests made with a single user tend to show results influenced by their experience, so use a group of users is required. For each disability who wish to make an evaluation, you need to have the help of a group of people with such disabilities. These results may again cause the application has new changes.

Another hypothesis was difficult to interpret the recommendations. This is true when there are more subjective evaluation criteria or can not be verified by automated tools, such as the content organization in a logical sequence or sequential arrangement of interactive elements. Considering the proposed process for drafting the framework, there is the record of the accessibility requirements success criteria in the style guide did not bring benefits. This stems from the fact that, for component production, not all success criteria apply directly to the platform interface elements (e.g. textbox, option button, listbox, etc.). Another relevant point during the preparation of the framework is the discovery of influences that recommendations have on the existence and behavior of user interface elements. There was, for example, the need for positioning change the selection box “Store password on this computer” to before the button “Confirm”, the User ID screen. This change stems from the need to put the items in a logical order. The new need for user interaction with the application has motivated the authors alter the use cases and specifications of components. During the development of the framework were carried out some tests with verification tools. The first components developed and tested had errors that go unnoticed and were singled out by verification tools. However, there are problems that are indicated by a tool and are ignored by others. Moreover, the tools produce results that need to be screened by the component developer and subsequently confirmed during an evaluation involving persons. The most obvious cases are related to false positives. The most obvious cases are the tests with the tables in which validators demanded an attribute that is not necessary when the cells are not merged. After the implementation of automated testing and verification by the developer, the site was evaluated by people with disabilities. Evaluation of accessibility allowed the authors to observe one of the causes for the long used by people with complete loss of vision: the combined use of different readers and browsers to accomplish a task. Although each volunteer has chosen a browser and a screen reader, all said that, in everyday life, use more than one browser or screen reader to accomplish the same task, depending on the seriousness of the task.

8 Conclusion

According to the proposed objective, it developed a framework of components as support accessibility. It was found that the conversion of the interaction pattern on use cases and domain model was positive. Examples found use nouns and names technique were applied to the statements of the problem. In this work, the technique has been successfully applied on the interaction pattern. The use of Nouns and Verbs technique allowed the identification of classes, attributes, operations and relationships, which were reused in the classification process, proving to be productive reuse of domain model and use cases as input for the conceptual model. It was shown that for the preparation of the style guide, some inputs are available and ready to be reused, requiring little or no adjustment. Interaction Patterns, specifications HTML and accessibility requirements were used to produce items of the style guide.

The artifact adaptation began to relate the accessibility requirements and their care, so that the use case has been adapted to receive a table that lists the accessibility requirements and its service according to the evaluator. Certain limitations have been mapped, for example, the number of steps for implementing the proposed method. The process proposed in attempts to follow all activities of usability engineering cycle and component specification process that are partially showing dispensable for the production of components for this work, although they may benefit from the existence of some inputs. For example: style guide screen design standards are concerned with message boxes and help windows, which are not part of the scope of this project. Another limitation is the subjectivity of the transformation of an interaction pattern on a prototype. Possession of interaction pattern, the developer shall prepare the prototype components with HTML controls set building on their personal experience. For example, when the default displays a field for the user name fill in a login screen, the developer probably assume that this field is a text box, and come to this conclusion based on his personal experience. Also related to subjectivity, it is a point of attention to Component Development from the specification and style guide. The artifacts used for Component Development programming language may no longer contain details, and it will take the developer to establish subjective criteria. For example, when developing the user authentication component, the developer must decide the size of the text boxes and their positions.

Research continues to develop with new challenges, such as considering the universal access, since the project was limited to the care of people with a type of perceptual constraint. In addition, a future project may involve processes that promote the reuse of accessible components; the development of other e-commerce components or general purpose; the development of frameworks available in other application domains.

References

1. Alexander, C., Isikawa, S., Silverstein, M., Jacobson, M., Fiksdahl-King, I., Angel, S.: A Pattern Language, 2nd edn. Oxford University Press, New York (1977)
2. Appleton, B.: Brad Appleton's, http://www.cmcrossroads.com/bradapp/
3. Brasil.: Ministério do Planejamento, e-MAG - Programa de Governos Eletrônico Brasileiro (2016), http://www.governoeletronico.gov.br/emag/
4. Brasil. DECRETO No 5.296, Diário Oficial da União: http://www.planalto.gov.br/ccivil_03/_ato2004-2006/2004/decreto/d5296.htm
5. British Standards Institution.: PAS 78. publicly available specification: a guide to good practice in commissioning accessible websites. UK (2006)
6. Butler, G., Dénommée, P.: Documenting frameworks to assist application developers. In: Fayad, M.E., Schmidt, D.C., Johnson, R.E. (eds.) Building Application Frameworks. John Wiley and Sons (1997)
7. Cheesman, J., Daniels, J.: UML Components—A Simple Process for Specifying Component-Based. I: Szyperski, C. (ed.) Addison-Wesley (2001)
8. Cockburn, A.: Writing Effective Use Cases. Addison-Wesley, USA (2001)
9. D'Souza, D.F., Wills, A.C.: Objects, Components, and Frameworks with UML: The Catalysis Approach. Addison-Wesley L. P. Co., Inc, Boston, MA, USA (1999)
10. Duyne, D.K., Landay, J.A., Hong, J.I.: Design Patterns at a Glance—The Design of Sites (2009), http://www.designofsites.com/design-patterns/
11. Encyclopaedia Itaú Cultural.: Aleijadinho (1730–1814) www.itaucultural.org.br/
12. Encyclopedia Brittanica—Britannica Online Encyclopedia (2016)
13. Fontoura, M.F.: A systematic approach to framework development. Tese de Doutorado, 165 f. Pontifícia Universidade Católica, Rio de Janeiro, 1999
14. Freire, A.P.: Acessibilidade no desenvolvimento de sistemas web: um estudo sobre o cenário brasileiro. Dissertação Mestrado. 154 f. USP, São Carlos (2008)
15. Freire, A.P., Goularte, R., Fortes, R.P. Techniques for developing more accessible web applications: a survey towards a process classification. In: ACM International Conference on Design of Communication, El Paso (2007)
16. Gamma, E., Helm, R., Johnson, R., Vlissides, J.: Design Patterns: Elements of Reusable Object-Oriented Software. Addison-Wesley L. P, Boston, MA, USA (1995)
17. Governo Brasileiro.: Material de Apoio do Programa de Governo Eletrônico Brasileiro (2016), In: http://www.governoeletronico.gov.br/acoes-e-projetos/e-MAG/
18. Instituto Brasileiro de Geografia e Estatística.: População residente, por tipo de deficiência, segundo a situação do domicílio e os grupos de idade – Brasil (2000)
19. Instituto Brasileiro de Geografia e Estatística (2016), In: http://www.ibge.gov.br/home/presidencia/noticias/
20. Jacobson, I.: Object-Oriented Software Engineering: A Use Case Driven Approach. Addison-Wesley, England (1992)

21. Johnson, R.E.: Documenting frameworks using patterns. In: Object-Oriented Programming Systems, Languages, and Applications, Vancouver, pp. 63–76 (1992)
22. Konrad, S., Cheng, B.H.: Requirements patterns for embedded systems. In: The IEEE Joint International Conference on Requirements Engineering. Essen, pp. 127–136 (2002)
23. Loiacono, E.T., Romano Jr., N.C., Mccoy, S.: The state of corporate website accessibility. Commun. ACM **52**(9), 128–132 (2009)
24. Mayhew, D.J.: The Usability Engineering Lifecycle: A Practitioner's Handbook for User Interface Design. Morgan Kaufmann (1999)
25. Petrie, H., Badani, A., Bhalla, A.: Sex, lies and web accessibility: the use of accessibility logos and statements on e-commerce and financial websites. In: Accessible Design in the Digital World Conference, Dundee (2005)
26. Pree, W.: Hot-spot-driven framework development. In: Summer School on Reusable Architectures in Object-Oriented Software Development, pp. 123–127 (1995)
27. Riehle, D., Züllighoven, H.: Understanding and using patterns in software development. In: Patterns Languages of Program Design, pp. 3–13, Addison-W. (1996)
28. Romano, J., Nicholas, C.: Customer relationship management for the web-access challenged: inaccessibility of fortune 250 business web sites. Int. J. Electron. Commer. **7**(2), 81–117 (2002)
29. Sommerville, I.: Sotware Engineering (8th edn.). Addison-Wesley (2007)
30. Sonza, A.P.: Ambientes Virtuais Acessíveis sob a perspectiva de usuários com limitação visual. 313 f. Tese (Doutorado) - UFRGS, Porto Alegre (2008)
31. Szyperski, C., Gruntz, D., Murer, S.: Component software—beyond object-oriented programming (2nd edn.). (A. Press, ed.) Addison-Wesley (2002)
32. The Institute of Electrical and Electronics Engineers, Inc. Std 830-1998.: IEEE Recommended Practice for Software Requirements Specifications. USA (1998)
33. U.K. Ministry Of Justice.: Disability Discrimination Act 2005 (www.legislation.gov.uk/ukpga/2005/13/contents)
34. U.S. Government.: Amendment to Section 508 of the Rehabilitation Act, 2016, In: http://www.access-board.gov/sec508/guide/act.htm
35. United Nations.: UN Enable—Convention on the Rights of Persons with Disabilities (2006), In: www.un.org/disabilities/default.asp?navid=12&pid=150
36. van Welie, M.: Interaction Design Pattern Library—Welie.com (2008), In: http://www.welie.com/patterns
37. Web Accessibility Initiative—W3C.: Conformance Evaluation of Web Sites for Accessibility (2016) http://www.w3.org/WAI/eval/conformance.html
38. Withall, S.: Software Requirement Patterns. Microsoft Press (2007)
39. World Bank.: Disability and Inclusive Development in Latin America & the Caribbean (2009) http://web.worldbank.org/
40. World Health Organization.: WHO|What is E-Accessibility? (2016), In: http://www.who.int/features/qa/50/en/index.html
41. World Wide Web Consortium.: 2016, In: http://www.w3.org/standards/
42. World Wide Web Consortium.: Web Content Accessibility Guidelines (WCAG) 2.0 (2008), In: http://www.w3.org/TR/WCAG20/

Development of Interactive System for Visually Impaired Using a Tactile Device

Kazuki Harada, Keisuke Usuda, Jose E. Oliveira, Juliene I.F. Moreira and Michiko Ohkura

Abstract Even though some studies have confirmed that visually impaired people have superior tactile sensation abilities, few systems based on these advantages have exploited. In this study, we developed and evaluated an interactive system that utilizes the superior abilities of the visually impaired to increase their enjoyment in a video game application. We employed the TECHTILE toolkit as a device to output tactile sensations and developed an interactive system with several types of tactile sensations. We created a system that has 3D content and a story using Unity and experimentally evaluated it.

Keywords Tactile sensation · TECHTILE toolkit · Visually impaired · Interactive system introduction

K. Harada (✉) · K. Usuda · M. Ohkura
Shibaura Institute of Technology 3-7-5 Toyosu, Koto-ku, Tokyo 135-8548, Japan
e-mail: al13088@shibaura-it.ac.jp

K. Usuda
e-mail: ma14018@shibaura-it.ac.jp

M. Ohkura
e-mail: ohkura@sic.shibaura-it.ac.jp

J.E. Oliveira
Av. Rodovia Senador José Ermírio de Moraes, 1425 - Alto Da Boa Vista, Sorocaba - SP 18087-125, Brazil
e-mail: the.moonest.one@gmail.com

J.I.F. Moreira
Pós-Graduação e Administração Geral – Ed. João Calvino - R. da Consolação, 930 - Consolação, São Paulo - SP 01302-907, Brazil
e-mail: julivyfy@gmail.com

M. Soares et al. (eds.), *Advances in Ergonomics Modeling, Usability & Special Populations*, Advances in Intelligent Systems and Computing 486,
DOI 10.1007/978-3-319-41685-4_48

1 Background and Development Purpose

In recent years, people crave not only material but also spiritual wealth [1]. For the latter, such interactive systems as video games effectively increase pleasure and feelings of solace and healing. However, since most video games are developed for the sighted, the visually impaired are not able to play them. Of course, some video games for the visual impaired using sound have been developed. However, since several studies have reported that the visually impaired have superior tactile sensation abilities [2], we developed an interactive system for the visually impaired by exploiting their superior tactile sensations [3]. In our previous study, we developed an interactive system using a tactile device called the TECHTILE toolkit [4]. In this article, we report a new interactive system with 3D content and a story that creates enjoyment for the visually impaired through sounds and tactile sensations.

2 System Design

We employed a TECHTILE toolkit to output tactile information. We also employed headphones to output sound and a mouse for control. The following shows the system's flow:

I. A PC outputs 3D sound information through headphones and tactile sensations through a TECHTILE toolkit by putting two oscillators between the two fingers on the left hand.
II. The PC outputs visual information through the display.
III. Players perform the game with a mouse using sound, tactile, and visual information. Completely blind players can play the game without any visual information (Fig. 1, 2, 3, 4, 5 and 6).

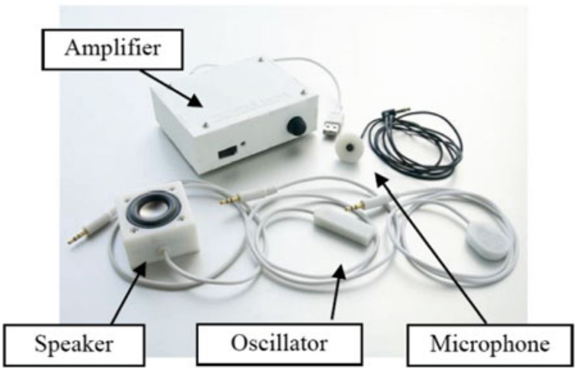


Fig. 1 TECHTILE toolkit [4]

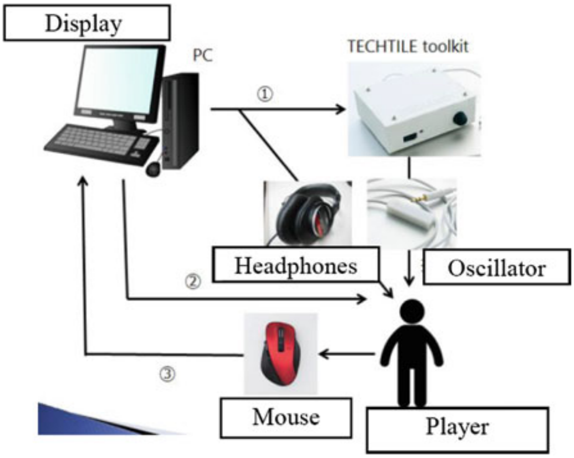


Fig. 2 System diagram

Fig. 3 Tutorial

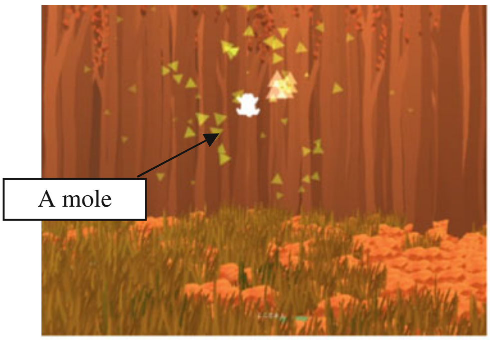


Fig. 4 Catching moles

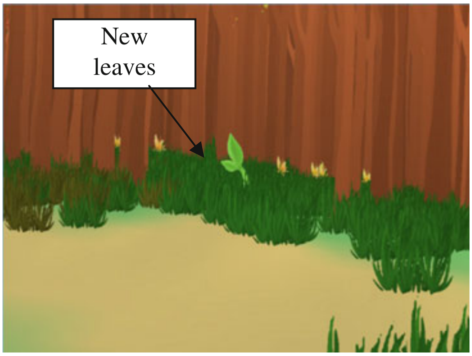


Fig. 5 New leaves start growing

Fig. 6 Picking up water

3 System Construction

3.1 Content

We created a video game with Unity that can create 3D space with 3D sound. Players play this video game with a mouse to move in 3D space and follow tactile, sound, and visual information. In this game situation, "the player is lost in the forest." Here are the following three main parts of the content:

I. Introduction: A voice explains the game situation, how to play and the goal of the game.
II. Catching moles: The player searches for moles based on tactile information and clicks the mouse at proper timing to capture them.
III. Watering the tree: The player moves to where she can scoop up water based on tactile information. She can carry water by pressing the mouse from this location. When the player successfully releases the button next to the tree, it starts to grow and the game ends.

Fig. 7 Experimental scene

Between the above two main parts, a part is inserted where the player chases singing birds.

3.2 *Playing Without Sight Information*

The player presses the mouse to learn which direction he/she should go based on a sound (e.g., ring). We call this navigation. In Fig. 7, when the direction in which the player should go is forward-left, the navigation provides a 3D sound from the forward-left. In the same manner, when the direction in which the player should go is right, the navigation provides a 3D sound from the right.

3.3 *Tactile and Sound Information*

Table 1 shows the main situations in the game with tactile and sound information. In this game, both the tactile and sound information have the same sound data. For example, when the player hits the wall, a low, short tone is output through the tactile and sound devices. In the same manner, other tactile and sound information output tones.

Table 1 Game situations and corresponding tactile and sound information

Game situation	Tactile and sound information
When player hits the wall	Low, short tone such as a bump
Mole moving underground	Low, long tone
Carrying water	High, short tone such as slapping
Walking on grass	Rustling tone

4 Evaluation Experiment

4.1 Outline

After a preliminary experiment and improvements to the system based on the results, we experimentally evaluated it by employing 16 sighted and 8 visually impaired participants. In this experiment, the half of the sighted people played the game with sleep masks.

4.2 Evaluation Method

Our questionnaire included a five-grade evaluation and free writing after the participants played the game. The visually impaired heard and answered by voice. The following are the questionnaire items from the experiment:

- Did you enjoy the game?
- Do you want to play it again?
- Were you impressed by the tactile information?
- Did you notice the game situations and how to play during the tutorial?
- Was the navigation easy to follow?
- How did you feel about the length of the playing time?
- How did you feel about the degree of difficulty?
- Were you impressed the mole moving?
- Were you impressed walking on the grass?
- Were you impressed walking on dry leaves?

4.3 Experimental Results and Discussion

Figure 7 shows an example of the experimental scene. Figure 8 shows a result of the following questionnaire item: "Did you enjoy the game?" (1: boring, 3: neutral, 5: very). Sighted with a sleep mask and the visually impaired commented the game contains tactile and sound information as well as a story. From these answers, we confirmed that the system was enjoyable for the visually impaired.

In the same manner, Fig. 9 shows the result of the following questionnaire item: "Did you notice the game situation and how to play during the tutorial?" (1: did not notice, 3: neutral 5: clearly noticed). The tutorial, which was easily recognized by the players, supported them.

Figure 10 shows the result of the following questionnaire item: "How did you feel about degree of difficulty?" (1: very difficult, 3: neutral, 5: very easy). Neither the visually impaired nor sighted without a sleep mask answered difficult. However,

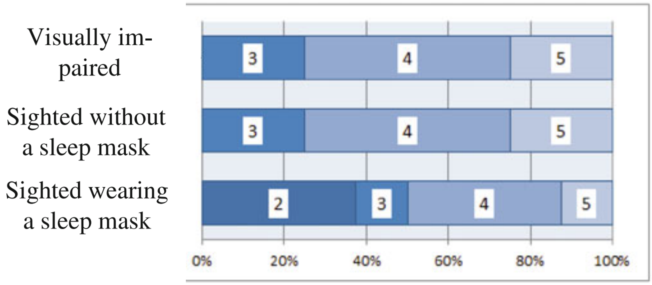


Fig. 8 Result of "did you enjoy the game?" item

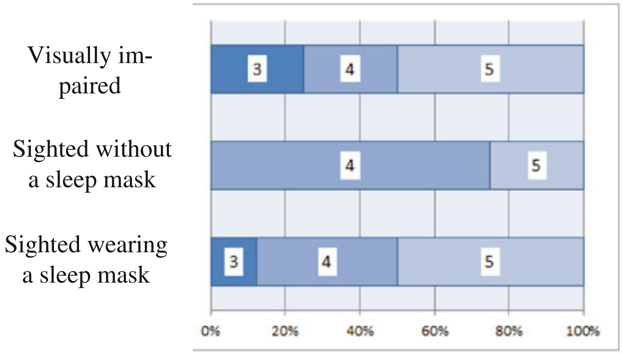


Fig. 9 Result of "did you notice game situation and how to play during tutorial?" item

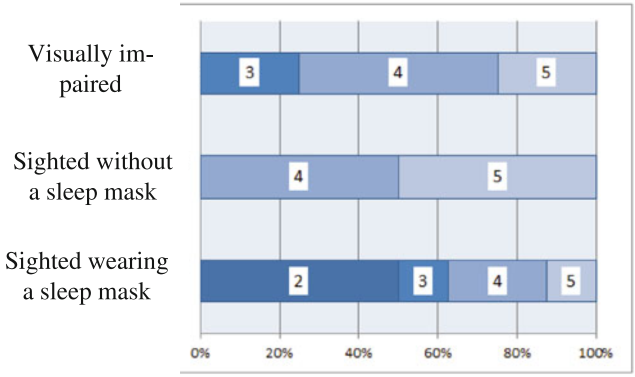


Fig. 10 Result of "how did you feel about degree of difficulty?" item

because some of the visually impaired did not recognize their positions in 3D space, we need to load a function to show player positions. Sighted without a sleep mask were satisfied since they could navigate with their vision.

Figure 10 shows the result of the following questionnaire item: "How did you feel about the degree of difficulty?" (1: very difficult, 3: neutral, 5: very easy). We analyzed the result by the Kruskal-Wallis test and found that it was statistically significant at the 1% level and confirmed the following:

$$\text{sighted without a sleep mask} > \text{sighted with a sleep mask}\ (p < 0.01)$$

$$\text{visually impaired} > \text{sighted with a sleep mask}\ (p < 0.10).$$

Therefore, we found that the visually impaired are able to play a complicated game more smoothly using tactile and sound information than sighted people wearing a sleep mask, probably because the visually impaired have superior tactile and sound sensation abilities. Most participants rated the degree of difficulty as 3, suggesting that the game's degree of difficulty was appropriate.

5 Conclusion

We developed and evaluated an interactive system for the visually impaired. The experiment results confirmed that most of our visually impaired participants enjoyed playing on the system. Most participants enjoyed playing the game by tactile and sound information. We also confirmed that the navigation functions that support the visually impaired increased their enjoyment of the game. Therefore, we not only achieved our objective to develop an interactive system for the visually impaired using the TECHTILE toolkit but also increased their spiritual wealth.

Acknowledgments We thank Mr. Teranishi, a teacher, and the students of the School for the Visually Impaired, the University of Tsukuba and students of our university for their participation in the experiment.

References

1. Cabinet Office, Government of Japan.: A public-opinion poll of the national life of Japan, http://survey.gov-online.go.jp/h26/h26-life/
2. Ohyama, T., Imai, S., Waki, T.: The Handbook of Perceptual Psychology and Sensation: Seishin Shobo (1994)
3. Ikegami. Y.: Development of interactive system for visually impaired using tactile information. In: The Research Paper of The Institute of Electronics, Information and Communication Engineers, WIT, vol. 109(358), pp. 25–28 (2010)
4. Minamizawa, K.: TECHTILE toolkit—A prototyping tool for design and education of hapticmedia. In: Proceedings of Laval Virtual VRIC'12, Laval, France, March (2012)

Part VI
Interface Design and Usability Evaluation for Healthcare and Safety

The Effect of Wearing Eyeglasses upon Postural Comfort Perception While Using Multi-tasking Electronic Devices in Sitting Position

Vito Todisco, Vito Clemente, Rosaria Califano and Mariarosaria Vallone

Abstract In this paper, the authors show the results of an anecdotic experiment about the effect the use of eyeglasses has on the body posture of people in seated positions using different kinds of electronic devices: a desktop computer, a laptop, a tablet and a smartphone. The tasks were performed using a fully reconfigurable seating buck on which a standard VDT (Video Display Terminal) workplace with a chair was set. Subjects performed different tasks in order to evaluate the subjective perception of postural comfort. A Digital Human Modeling system was used to model and evaluate, from an ergonomic point of view, the ergonomic level. Software CaMAN®, was used to perform an objective evaluation of the postural comfort of subjects' upper limbs and to compare the results obtained for the different subjects. The results show that the use of glasses has a significant effect on the body postures of the subjects.

Keywords Glasses · Comfort · Discomfort · Posture · VDT/computer workplace · Electronic devices

V. Todisco (✉) · V. Clemente · R. Califano · M. Vallone
Department of Industrial Engineering, University of Salerno, Via Giovanni Paolo II 132, 84084 Fisciano (SA), Italy
e-mail: ace.nasseo@gmail.com

M. Vallone
e-mail: mvallone@unisa.it

M. Soares et al. (eds.), *Advances in Ergonomics Modeling, Usability & Special Populations*, Advances in Intelligent Systems and Computing 486,
DOI 10.1007/978-3-319-41685-4_49

1 Introduction

Although the use of a computer may not appear to be physically tiring, to maintain a sitting posture and to perform repetitive tasks for long periods of time may lead to injuries that can compromise the good health and quality of life of a worker. The use of common electronic devices can, in fact, involve inappropriate postures and lead to stress of upper body limbs. During the last decade, a number of researchers and designers have made improvements to the ergonomics and comfort of products, work cells and workstations. The most commonly used method for ergonomic analysis is based on the following two steps:

1. Direct and indirect (videotaped) observations of users and workplaces;
2. Information collection about work-cells and work-cycles.

Considerable research has resulted in many papers dealing with perceived levels of comfort/discomfort, but the majority of these discuss the relationship of comfort levels to environmental factors—such as temperature, humidity, applied forces [1]—or assume that a relationship exists between self-reported discomfort and musculoskeletal diseases [2]. Five main subjects of consideration regarding the relationship between the subjective perception of comfort/discomfort and the factors relating to products, processes, interactions, environment, and users, have been identified and are recognized by most scientists: Sensory input [3, 4]; Activities that influence comfort conducted during the measurement [5–7]; Different body regions [8, 9]; Effect of product contours on comfort [10–13]; Physical loading [14–17]. In [18] there is an interesting schematization of the mechanism of comfort/discomfort perception that comes from the Moes' model [19]. It was developed in 2012 by Vink and Hallbeck [18] and finally was upgraded by Naddeo et al. [20], as shown in Fig. 1 (I = Interaction; H = Human body effects, P = Perceived Comfort, C/N/D = Comfort/Nothing/Discomfort), to take into account expectations (E) and perception modifications due to the qualities of testing devices.

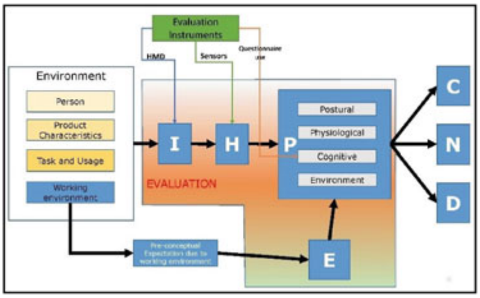


Fig. 1 Cappetti and Naddeo comfort/discomfort perception model

In this model, the body and perceived effects play a fundamental role in comfort/discomfort perception and evaluation. Defining the maximum level of comfort attainable by human postures seems to be one of the most important tasks of this type of comfort evaluation model [21–24], especially if the determination of the maximum comfort level is based on the measurement of the angular range of motion (ROM) of each joint.

Certain medical studies have shown that every joint has a natural rest posture (RP) [25, 26], wherein the muscles are completely relaxed or at a minimum strain level: When this occurs, the geometrical configuration of joints corresponds to the natural position of the resting arms, legs, neck, and so forth. This position appears to minimize musculoskeletal disease and optimize comfort perception [1].

Papers [27] and [28] present a new software named CaMAN® that is based on posture analysis. This software allows making quantitative evaluations of postural comfort.

The aim of this paper is to evaluate the postures assumed by subjects when using four kinds of devices (desktop computer, laptop, smartphone, tablet), in order to determine whether and how the wearing of glasses influences upper body limbs in terms of comfort. Naturally, the body movements are involved with and connected to the desire to obtain a good view of the device; in fact, to achieve a good view the body assumes specific postures [29–32]. The posture of the head is the most important and most closely related to having a good view [31, 33]. Forward flexion of the neck creates an increased moment of the head weight that can produce significant contraction of the muscles to achieve equilibrium [34, 35].

In VDT work, the head must constantly monitor the screen and, thus, it is very important to evaluate the postural comfort of the head and the other body parts. This is particularly important in interactive work, such as computer-aided design (CAD), where 50 % of the working time is spent watching a display [36].

Some authors have studied how posture can be improved by changing the design of the workstation. Increasing the VDT monitor height has resulted in the head not being bent as far and a trunk that is more erect [32, 37]. This erect posture may produce less muscle tension and less load on the spine compared to a flexed upper body [30, 38]. In [39], a comfort based tool for dashboard analysis has been developed for objects' positioning.

In [40], a workstation was manipulated in order to determine the changes in the body positions and the electromyographic (EMG) activities of the neck extensor muscle and the descending part of the trapezius muscle. The VDT screen height was modified while performing tasks that were not keyboard related. The relationship between posture and muscle activity at the different screen height settings was explored. A simulation of muscular activation towards postural comfort has been developed, by using AnyBody® Software in [41].

2 Purpose

The aim of this study was to investigate the impact of wearing eyeglasses on the postures of body upper limbs when subjects were in a sitting position using different electronic devices.

During the experimental phase, the subjects utilized different electronic devices, each for a certain period of time, maintaining themselves in what they determined to be the most comfortable position.

3 Participants

Two male students from the Department of Industrial Engineering at the University of Salerno participated in the experiment. The two students were both 24 years old and were similar in body-shape and size (arms' and legs' length, height, and weight) and had few anthropometric differences (about 60° human percentile for the South European Population).

The subjects were informed of the nature of the tests and their written consent, in accordance with ethical standards of the University of Salerno, was obtained.

4 Apparatus

Subjects were seated for analysis in a seating buck (Fig. 2a) realized in the Virtual Prototyping laboratory of the University of Salerno. The seating buck is a fully reconfigurable system, and is used to carry out ergonomic and comfort evaluations.

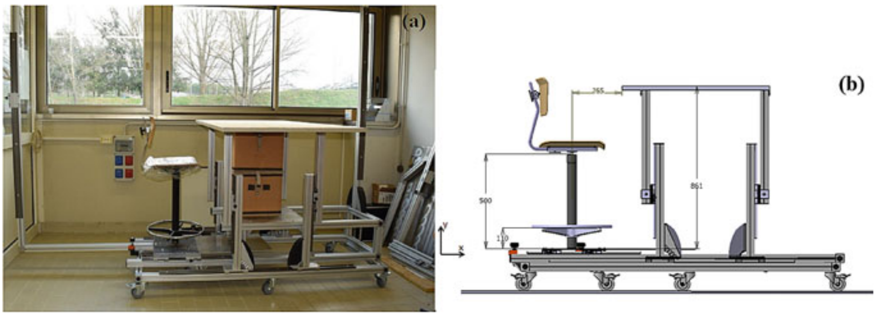


Fig. 2 **a** Seating buck; **b** virtual seating buck model configuration

In this study, the seating buck was set as an office desk with stool-type seating that had adjustable height and a footrest.

Figure 2b shows the height of the seating buck workbench and seat used for the experiment. Both subjects used the same test setup.

5 Procedure

The subjects (C and T) sat themselves in the seating buck location and used each of the four devices, one at a time.

The procedure for using each of the devices was the same:

- Each subject positioned himself according to his preferences and used the device as he would ordinarily do;
- For each device (desktop computer, laptop, smartphone and tablet), the postures of the subjects were acquired through two photos: one from the lateral side and the other from the back side. A third photo was acquired in order to reproduce each subject's binocular vision and evaluate the hand angles with more accuracy;
- The photos were processed by the software Kinovea® in order to acquire the angles of body joints;
- The acquired angles were input in Delmia® in order to simulate each posture. In this step, some assumptions were made to ensure the correspondence between the angles evaluated by two different software (Kinovea® and Delmia®). Delmia® was used to evaluate accurately angles that were not available through the photographic acquisition, such as arm medial rotation, forearm pronation/supination and hand flexion/extension, as well radio-ulnar deviation;
- The upper limb angles were processed by CaMAN® in order to obtain both partial comfort indices and a global comfort index, by which we could validate the analysis of the results.

In this study, the postural analysis considered only the upper limbs. It was observed that, for each device, there were different dispositions of the articular joints of the upper limbs, while for the lower limbs, the posture was quite similar for all the devices.

6 Comfort Index

Each posture can be defined by several anthropometric parameters. These parameters are the angles of each joint [28] required to associate a comfort score with each parameter. Comfort scores were calculated for each joint using the CaMAN®

software and then were combined according to criteria that synthesize the posture comfort index.

In order to render a clearer result, comfort scores were compared using two different criteria: the sum and the mean. A global comfort index can be defined as context sensitive because it uses different combination rules, the most common being the minimum, maximum, arithmetic/weighted mean, geometric mean, and sum.

The sum and the arithmetic mean are two simple and significant criteria that allow an initial evaluation of the posture comfort index and that have been chosen for this case.

The angles considered in CaMAN® are related to the more stressed joints that have a higher weight in the posture comfort index evaluation.

7 Results

Each posture for the subjects was examined taking into account the individual comfort indices related to several joints. The analyzed postural angles were related to the shoulder, elbow and neck. The analyses of the postures assumed by the subjects were used to explain the effect of wearing eyeglasses upon postural comfort perception when subjects used different electronic devices in a sitting position.

The results were also submitted to a sensitivity analysis: it was demonstrated that a small variation of the angles, compared to those previously inserted, caused small changes in the comfort indices. This ensured that the results were reliable.

7.1 Posture While Using a Desktop Computer with Monitor and Keyboard

The use of a desktop computer was simulated by placing a monitor and a keyboard on the seating buck table.

The results of the postural comfort indices for each subject are shown in Table 1. The global comfort indices were similar to each other with some differences for the elbow and shoulder.

Table 1 Comfort perceptions using desktop computer

	Monitor and keyboard				
Part of body	Angles			Comfort index	
	Limb	C	T	C	T
Shoulder	Flexion	18	32	9.6	7.78
	Abduction	14	11	9.8	9.99
Elbow	Flexion/extension	76	51	6.05	7.09
	Pronation/supination	−70	−70	1	1
Neck	Flexion	−17	−11	8.56	8.95
	Rotation	0	0		
	Lateral	0	−1	9.9	9.9
Sum				45	44.71
Average				7.50	7.45

Fig. 3 **a** Angles acquisition by *Kinovea*®, left-side view, subject T; **b** Angles acquisition by *Kinovea*®, left-side view, subject C; **c** Angles acquisition by *Kinovea*®, back side view, subject T; **d** Angles acquisition by *Kinovea*®, back side view, subject C

Subject T assumed a posture more extended backwards, inducing a greater upper limbs flexion (Fig. 3). By contrast, C assumed a straight back posture with the trunk more forward, resulting in a lower arm flexion but a consequently larger forearm flexion.

The neck comfort indices were quite similar, though the result for C was slightly lower due to a larger flexion. The differences in the neck postures of the subjects were very small and these did not affect the neck comfort indices. The differences in the upper limb postures were significant, providing a more comfortable posture for T than C, since C had a higher elbow flexion.

Table 2 Comfort perceived using laptop

Part of body	Laptop				
	Angles			Comfort index	
	Limb	C	T	C	T
Shoulder	Flexion	24	22	8.75	9.11
	Abduction	9	12	10	9.95
Elbow	Flexion/extension	74	72	6.15	6.27
	Pronation/supination	−75	−58	1	1.2
Neck	Flexion	−28	−19	7.7	8.55
	Rotation	0	0		
	Lateral	0	−2	9.9	9.9
Sum				43.5	44.98
Average				7.25	7.50

Table 1 reports upper limbs angles taken from CaMAN® and the comfort indices for both subjects.

7.2 Posture While Using the Laptop

This posture was simulated by placing the laptop on the table so that its edge was coincident with the table's edge.

Compared to the desktop computer, the laptop had a smaller screen surface and a built-in keyboard. As a result of these characteristics, the subjects had to bring the laptop closer to themselves and reduced the visual field in doing so.

The results of the postural comfort indices for each subject are shown in Table 2.

The comfort evaluation showed that the global comfort index was quite similar for the two subjects. Although the two subjects assumed roughly similar postures (Fig. 4), their neck flexion was considerably different. The differences in the postures were due to the eyeglasses. Subject C needed to incline his neck more than T to focus on the laptop screen through the lenses. Subject T, not having the constraint imposed by the eyeglasses, could compensate for neck flexion with eye rotation. Eye rotation of this kind was not possible for C because the frame of the eyeglasses would have impeded his line of sight. As explained, the presence of the eyeglasses caused C to have neck flexion 9° greater than T and this resulted in less comfort.

Fig. 4 **a** Angles acquisition by *Kinovea*®, left-side view, subject C; **b** angles acquisition by *Kinovea*®, left-side view, subject T; **c** angles acquisition by *Kinovea*®, back side view, subject C; **d** angles acquisition by *Kinovea*®, back side view, subject T

7.3 Posture While Using the Tablet

Tablets can be used in various ways, depending the user's preferences. To simulate tablet use in this study, the device was laid flat on the table and the subjects were seated.

Table 3 shows that the values for the angles and for comfort perceptions were very different.

The two subjects assumed similar postures when using tablet; both inclined their trunks and heads (Fig. 5).

Because tablets are smaller than the devices previously analyzed and because of the position chosen for the tablet, the visual field was reduced.

When using the tablet, both subjects tended to flex mainly the neck to focus on the device and to assume the most comfortable position. This was the case because the position of the tablet near the edge of table was closer to the subjects than the other devices had been.

Table 3 Comfort perceived using tablet

	Tablet				
Part of body	Angles			Comfort index	
	Limb	C	T	C	T
Shoulder	Flexion	10	7	9.9	9.97
	Abduction	12	13	9.95	9.88
Elbow	Flexion/extension	90	90	5.6	5.6
	Pronation/supination	−80	−49	1	4.01
Neck	Flexion	−42	−38	6.1	6.7
	Rotation	0	0		
	Lateral	0	0	9.9	9.9
Sum				43.5	46.06
Average				7.08	7.68

Fig. 5 **a** Angles acquisition by *Kinovea*®, left-side view, subject T; **b** angles acquisition by *Kinovea*®, left-side view, subject C; **c** angles acquisition by *Kinovea*®, backside view, subject T; **d** angles acquisition by *Kinovea*®, backside view, subject C

To offset the neck flexion, subject T moved his eyes more than he had when using the laptop. Moreover, the choice of posture was dependent on the fact that the tablet was laid flat on the table; the experiment did not allow the possibility to incline it. In fact, use of the tablet laid flat on the table is more comfortable than holding it in the hands, because the latter method induces higher stress of upper limbs if they are extended for a long period of time.

The study underlines the fact that the subject who wears eyeglasses requires greater neck flexion. Table 3 shows that the global comfort index is influenced mainly by elbow pronation/supination and minimally by the neck flexion.

7.4 Posture While Using the Smartphone

A typical way to use a smartphone is to hold it between the hands while resting the forearms on a table. During the use of the smartphone, the two subjects assumed the same posture that resulted in the most comfort for both (Fig. 6).

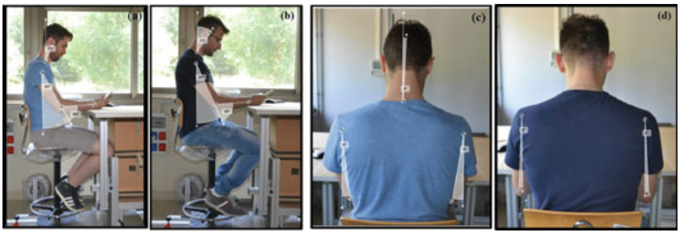


Fig. 6 **a** Angles acquisition by *Kinovea*®, left-side view, subject T; **b** angles acquisition by *Kinovea*®, left-side view, subject C; **c** angles acquisition by *Kinovea*®, back side view, subject T; **d** angles acquisition by *Kinovea*®, back side view, subject C

Table 4 Comfort perceived using smartphone

	Tablet				
Part of body	Angles			Comfort index	
	Limb	C	T	C	T
Shoulder	Flexion	24	28	8.75	8.22
	Abduction	2	−9	10	10
Elbow	Flexion/extension	68	64	6.53	6.75
	Pronation/supination	−20	−30	10	10
Neck	Flexion	−33	−23	7.2	8.2
	Rotation	0	0		
	Lateral	0	−2	9.9	9.9
Sum				52.38	53.07
Average				8.73	8.85

For subject T there was a smaller neck flexion, because the subject tended to delimit the neck flexion in order to compensate for eye rotation. The situation was different for subject C who wore eyeglasses. His neck flexion was greater than that of subject T because, in order to not to have his vision impeded by the eyeglasses, he had to flex the head more to have a better view of the device.

According to Table 4, this was the worst test case in terms of comfort, since the wearing of glasses had a considerable influence on the local comfort index related to neck inclination. As a result of wearing glasses, subject C was forced to flex the neck 10° more than subject T. He would have been able to adopt a more comfortable position without glasses.

8 Discussion

The study presented the parameters that affected the comfort indices of two subjects, one of whom wore eyeglasses and one of whom did not, when they used common electronic devices. Differences in neck flexion results were the most important parameter because neck flexion was constrained by the dimension, the shape and the position of the device.

In particular, the angle that identified neck flexion could be assumed to be constant for the entire time the subject used the device. Moreover, the user who wore glasses had a limit imposed on the visual field (due to the frames of the glasses) that required him to assume a less comfortable posture. Subject C needed

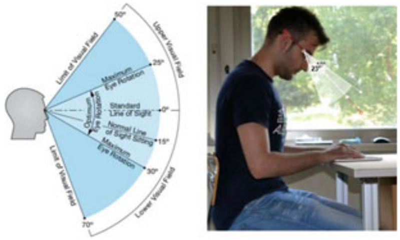


Fig. 7 Subject C's visual field limitation

greater flex of the neck and this resulted in more postural stress than he would have experienced if he did not wear glasses. This is especially the case if the position is held for a long period of time. It was also clear that subject C's neck setting (through his flexion) influenced all the angles of the upper limb articulations. Furthermore, the results obtained allowed us to quantify a difference in the neck frontal flexion of about 10° between a person wearing and one not wearing glasses.

This study examined only two subjects. Future research could extend this analysis by undertaking a study with more subjects in order to produce statistically more reliable results. Furthermore, the research activity could take into consideration a wider range of applications in carrying out the study.

Figure 7 shows an examination of subject C's visual field limitation in one of the four test cases (i.e. while he was using the tablet). On the left, we can see a typical human visual field range [42], while on the right the visual field range that results from C's neck flexion due to glasses is shown. The evaluation was done by drawing a perpendicular line to the lens. This line allowed us to recognize the origin of two angles: the upper visual field angle and the lower visual field angle. Then, to define the angles' edges, the vertex of the angles was arranged in center of eye rotation and another point was taken on the lens end. The sum of angles found (10° for the upper visual field and 23° for the lower one) gave the visual cone a width, and this width was lower than that of the subject who did not wear glasses.

It is clear that the results of this evaluation will vary with respect to both the dimensions of the lenses and the thickness of the eyeglasses' frames.

References

1. Galinsky, T.L., Swanson, N.G., Sauter, S.L., Hurrell, J.J., Schleifer, L.M.: A field study of supplementary rest breaks for data entry operators. Ergonomics **43**, 622–638 (2000)
2. Naddeo, A., Memoli, S.: Postural comfort inside a car: development of an innovative model to evaluate the discomfort level. SAE Int. J. Passeng. Cars Mech. Syst. **2**(1), 1065–1070 (2009)
3. De Korte, E.M., Huysmans, M.A., De Jong, A.M., Van de Ven, J.G.M., Ruijsendaal, M.: Effects of four types of non-obtrusive feedback on computer behavior, task performance and comfort. Appl. Ergon. **43**, 344–353 (2012)

4. Vink, P., Bazley, C., Kamp, I., Blok, M.: Possibilities to improve the aircraft interior comfort experience. Appl. Ergon. **43**, 354–359 (2012)
5. Groenesteijn, L., Ellegast, R.P., Keller, K., Krause, F., Berger, H., De Looze, M.P.: Office task effects on comfort and body dynamics in five dynamic office chairs. Appl. Ergon. **43**, 320–328 (2012)
6. Ellegast, R.P., Keller, K., Groenesteijn, L., Krause, F., Berger, F., Vink, P.: Comparison of four specific dynamic office chairs with a conventional office chair: impact upon muscle activation, physical activity and posture. Appl. Ergon. **43**, 296–307 (2012)
7. Franz, M.M., Durta, A., Zenk, R., Desmet, P.M.A.: Comfort effects of a new car headrest with neck support. Appl. Ergon. **43**, 336–343 (2012)
8. Kong, Y.U., Kim, D.M., Lee, K.S., Jung, M.C.: Comparison of comfort, discomfort, and continuum ratings of force levels and hand regions during gripping exertions. Appl. Ergon. **43**, 283–289 (2012)
9. D'Oria, C., Naddeo, A., Cappetti, N., Pappalardo, M.: Postural analysis in HMI design: an extension of OCRA standard to evaluate discomfort lever. J. Achievements Mater. Manuf. Eng. **39**, 60–70 (2010)
10. Kamp, I.: The influence of car seat design on its character experience. Appl. Ergon. **43**, 329–335 (2012)
11. Noro, K., Naruse, T., Lueder, R., Nao, N., Kozawa, M.: Application of Zen sitting principles to microscopic surgery seating. Appl. Ergon. **43**, 308–319 (2012)
12. Borg, G.: Psychophysical bases of perceived exertion. Med. Sci. Sports Exerc. **14**, 377–381 (1982)
13. Kee, D., Lee, I.: Relationships between subjective and objective measures in assessing postural stresses. Appl. Ergon. **43**, 277–282 (2012)
14. Di Pardo, M., Riccio, A., Sessa, F., Naddeo, A., Talamo, L.: Methodology development for ergonomic analysis of work-cells in virtual environment. SAE Technical Papers. doi:10.4271/2008-01-1481 (2008)
15. Zenk, R., Franz, M., Bubb, H., Vink, P.: Spine loading in automotive seating. Appl. Ergon. **43**, 290–295 (2012)
16. Vink, P., Hallbeck, S.: Editorial: comfort and discomfort studies demonstrate the need for a new model. Appl. Ergon. **43**, 271–276 (2012)
17. Moes, N.C.C.M.: Analysis of sitting discomfort, a review. In: Bust, P.D., McCabe, P.T. (eds.) Contemporary Ergonomics, pp. 200–204. Taylor & Francis, London (2005)
18. Naddeo, A., Cappetti, N., Vallone, M., Califano, R.: New trend line of research about comfort evaluation: proposal of a framework for weighing and evaluating contributes coming from cognitive, postural and physiologic comfort perceptions. In: Vink, P. (ed.) Advances in Social and Organizational Factors. Published By "Advances in Human Factors and Ergonomics" Conference 2014, ISBN 978-1-4951-2102-9 (2014)
19. Annarumma, M., Pappalardo, M., Naddeo, A.: Methodology development of human task simulation as PLM solution related to OCRA ergonomics analysis. In: Cascini, G. (ed) IFIP International Federation Information Processing, vol. 277, pp. 19–29. Springer (2008)
20. Tilley Alvin, R., Dreyfuss, H.: The Measure of Man and Woman: Human Factors in Design. Wiley & Sons Inc., New York. ISBN 978-0471099550 (2001)
21. Cappetti, N., D'Oria, C., Naddeo, A.: New comfort evaluation criteria: application on movie-theatre design. In: IMProVe—Proceedings, pp. 0–06. Libreria Cortina, Venezia (2011)

22. Apostolico, A., Cappetti, N., D' Oria, C., Naddeo, A., Sestri, M.: Postural comfort evaluation: experimental identification of range of rest posture for human articular joints. Int. J. Interact Des. Manuf. 1–14 (2013)
23. Fagarasanu, M., Kumar, K., Narayan, Y.: Measurement of angular wrist neutral zone and forearm muscle activity. Clin. Biomech. **19**, 671–677 (2004)
24. Christensen, H.W., Nilsson, N.: The ability to reproduce the neutral zero position of the head. J. Manipulative Physiol. Ther. **22**(1), 26–28 (1999)
25. Naddeo, A., Cappetti, N., Ippolito, O.: Dashboard reachability and usability tests: a cheap and effective method for drivers' comfort rating. SAE Technical Papers. (2014). doi:10.4271/2014-01-0455
26. Naddeo, A., Cappetti, N., D'Oria, C.: Proposal of a new quantitative method for postural comfort evaluation. Int. J. Ind. Ergon. **48**, 25–35 (2015)
27. Laville, A.: Postural reactions related to activities on VDU. In: Grandjean, E., Vigliani, E. (eds.) Ergonomic Aspects of Visual Display Terminals, pp. 167–74. Taylor & Francis, London (1980)
28. Colombini, D., Occhipinti, E., Frigo, C., Pedotti, A., Grieco, A.: Biomechanical, electromyographical and radiological study of seated postures. In: Corlett, N., Wilson, J., Manenica, I. (eds.) The Ergonomics of Working Postures: Models, Methods and Cases, pp. 331–44. Taylor & Francis, London (1986)
29. Nakaseko, M., Morimoto, K., Tanaka, H.: An image analyzing approach to working postures for screen and keyboard use of visual display units. In: Luczak, H., Cakir, A., Cakir, G. (eds.) Work With Display Units, vol. 92, pp. 235–239. Elsevier (1993)
30. Villanueva, M.B.G., Sotoyama, M., Jonai, H., Takeuchi, Y., Saito, S.: Adjustments of posture and viewing parameters of the eye to changes in the screen height of the visual display terminal. Ergonomics **39**, 933–945 (1996)
31. Hamilton, N.: Source document position as it affects head position and neck muscle tension. Ergonomics **39**, 593–610 (1996)
32. Kumar, S., Scaife, W.G.S.: A precision task, posture and strain. J Safety Res. **11**, 28–36 (1979)
33. Snijders, C.J., Hoek van Dijke, G.A., Roosch, E.R.: A biomechanical model for the analysis of the cervical spine in static posture. J Biomech. **24**, 783–792 (1991)
34. Van der Heiden, G.H., Brauninger, U., Grandjean, E.: Ergonomic studies on computer aided design. In: Grandjean, E. (ed.) Ergonomics and health in modern offices, pp. 119–128. Taylor & Francis, London (1984)
35. De Wall, M., Van Riel, M.P.J.M., Aghina, J.C.F.M., Burdorf, A., Snijders, C.J.: Improving the sitting posture of CAD/CAM workers by increasing VDU monitor working height. Ergonomics **35**, 427–436 (1992)
36. Schuldt, K., Ekholm, J., Harms-Ringdahl, K., Nemeth, G., Arborelius, U.: Effects of changes in sitting work posture on static neck and shoulder activity. Ergonomics **29**, 1525–1537 (1986)
37. Villanueva, M.B.G., Jonai, H., Sotoyama, M., Hisanaga, N., Takeuchi, Y., Saito, S.: Sitting posture and neck and shoulder muscle activities at different screen height settings of the visual display terminal. Ind. Health **35**, 330–336 (1997)
38. Schuldt, K., Ekholm, J., Harms-Ringdahl, K., Nemeth, G., Arborelius, U.: Effects of changes in sitting work posture on static neck and shoulder activity. Ergonomics **29**, 1525–1537 (1986)
39. Naddeo, A., Apicella, M., Galluzzi, D.: Comfort-driven design of car interiors: a method to trace iso-comfort surfaces for positioning the dashboard commands. SAE Technical Papers No. 2015-01-1394. doi:10.4271/2015-01-1394 (2015)
40. Villanueva, M.B.G., Jonai, H., Sotoyama, M., Hisanaga, N., Takeuchi, Y., Saito, S.: Sitting posture and neck and shoulder muscle activities at different screen height settings of the visual display terminal. Ind. Health **35**, 330–336 (1997)

41. Trapanese, S., Naddeo, A., Cappetti, N.: A preventive evaluation of perceived postural comfort in car-cockpit design: differences between the postural approach and the accurate muscular simulation under different load conditions in the case of steering-wheel usage. SAE Technical Papers No. 2016-01-1434. (2016)
42. Extron Electronics. http://www.extron.com/company/article.aspx?id=environconhumanfact&tab=technology

Preliminary Study on the Evaluation of Musculoskeletal Risk of Static-Cycling Instructors Using Infrared Thermography

Blanca Flores, Orlando Susarrey, Amalia Yoguez, Claudia Gutiérrez and José Jiménez

Abstract Currently, sports activities are considered occupational activities. Cyclists are vulnerable to develop musculoskeletal injuries related to overuse. A static-cycling instructor can teach professional cycling from 3 to 4 h a day. Constantly, they suffer discomfort and pain in the back. The purpose of this work is to develop a protocol to monitor the temperature of the skin at the back of static-cycling practitioners. The study was conducted by monitoring the temperature of the skin in the back, using infrared thermography. Three men and three women participated practicing static-cycling, the first thermal image was taken at rest, and then thermal images were taken every 15 min. The experimental work was carried out using two different types of bicycles. The data obtained in this study may be useful for the design of new products that enhance comfort in cyclists in order to reduce the risk of musculoskeletal injuries.

Keywords Infrared thermography · Musculoskeletal injuries · Back · Comfort · Static-cycling

1 Introduction

Due to technological development, new methods have been used for the evaluation of muscle fatigue, which can be used to improve health and safety at work for different people. In recent years, infrared thermography (IR) has been widely used in various fields of health. Some studies have reported that infrared thermography has capabilities to detect muscle disorders related to skeletal work. Muscle fatigue

B. Flores (✉) · O. Susarrey · C. Gutiérrez · J. Jiménez
Escuela Superior de Ingeniería Mecánica Y Eléctrica, Instituto Politécnico Nacional, Unidad Profesional "Adolfo López Mateos" Edificio 5 Tercer Piso, Col.Lindavista Cp, 07738 México City, D.F, Mexico
e-mail: floresblanca03@hotmail.com

A. Yoguez
Atepoxco 74, Col. Tepeyac Insurgentes, Cp, 07020 México City, D.F, Mexico

M. Soares et al. (eds.), *Advances in Ergonomics Modeling, Usability & Special Populations*, Advances in Intelligent Systems and Computing 486,
DOI 10.1007/978-3-319-41685-4_50

related to the excessive burden of muscle can become the source of the discomfort associated with skeletal muscle system [1]. An advantage of infrared thermography is the ability to measure the surface temperature of the human body without contact [2].

Exercise is recommended universally to maintain good health, lack of physical activity is an important risk factor for developing chronic diseases, cycling in all its forms is often recommended as an exercise. As more and more people are involved in any form of cycling, physicians should be aware of the common injuries caused by this activity [3]. Sports activities increase heart rate, which induces the body to the complex process of thermoregulation where some of the heat is dissipated through the skin [4]. When exercising, the metabolic rate increases to meet the needs of the human body, approximately 30–70 % of the energy produced during muscle contraction is dissipated as heat. The skin temperature during exercise may be related to muscular work reflecting the efficiency of the body to dissipate heat produced and at the same time this depends on the circulatory system and sweat rate [5]. Recently, infrared thermography has become popular in exercise physiology to infer production and heat dissipation [6].

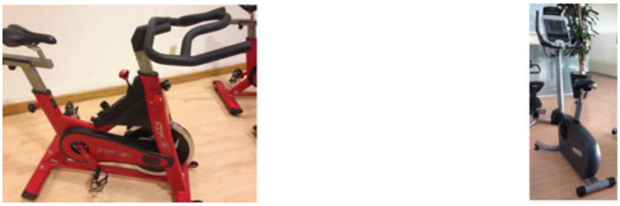
Physical activity naturally increases muscle metabolism, which may lead to increase the temperature in the muscles and the body due to heat generation. In these circumstances, the surface temperature of the body changes as a result of the body thermoregulatory mechanism [7]. Bikes have evolved significantly in recent decades as a result of technology, and the comfort of cyclists has become a critical design issue. The perception of comfort of cyclists has received little attention in the field of scientific literature [8].

During cycling, lower extremities are kept in constant motion, users of stationary bikes are at risk of musculoskeletal injuries when they force themselves to keep the pedaling pace. Sometimes, due to fatigue conditions users strained their backs causing pain or muscle discomfort. Some authors mention that an incorrect setting of the bike predispose users to injury and reduce performance on the bike. There is no agreement between the scientific and training communities regarding the optimal configuration of the bicycle [9].

2 Materials and Methods

2.1 Selection of Study Subjects

Three men and three women were invited to participate in the study, including a professional static-cycling instructor with over 20 years of experience in fitness classes and static-cycling.



a) Bike A b) Bike B

Fig. 1 **a** Bike A: static bike with adjustable seat height and handlebars and a knob to control pedaling resistance. **b** Bike B: static bike with adjustable seat height and preset pedaling resistance programs

2.2 Materials

The experiment was carried out in a classroom used for the practice of static cycling. FLIR E40 thermal camera was used with an original calibration certificate, temperature range from −20 to 650 °C, a thermal sensitivity of <0.07 °C @ 30 °C., IR resolution 160 × 120, picture frequency of 60 Hz spectral range 7.5 to 13 microns. Two different types of stationary bikes were used. The experiment was also divided into 2 phases: (a) a static bike with a height-adjustable seat, handlebars and a knob to control pedaling resistance (see Fig. 1a) and (b) a static bike with adjustable seat height and preset resistance pedaling programs (see Fig. 1b).

2.3 Protocol

Participants were informed about the exclusion criteria as being free of chronic diseases, no colds or any disease that affects their body temperature, and not under any medical treatment [10]. They were asked to have the disposition to uncover their back to capture thermal images and wear cotton clothes. Participants reported their consent for the study, as well as their availability and interest to participate in future studies.

Participants of both genders were gathered in a group in order to apply the same pedaling conditions at a high performance static-cycling session.

2.3.1 Phase One

This session was coached by the cycling instructor, which is more experienced in using Bike A. The first thermal imaging was taken with each participant at rest, then the session began pedaling for 60 min without rest periods, every 15 min the capture of thermal imaging was performed for each participant.

2.3.2 Phase Two

A second session of cycling using Bike B. During the test period, thermal imaging capture was performed every five minutes up to 20 min. In this test, participants used the same preset cycling program. All images were taken by the same person which is trained in thermography. All images were processed using an emissivity factor of 0.98 for the skin temperature [6].

3 Results

After evaluation of the thermographic images; in Fig. 2, the temperature variation in the back of the female participants is observed. Figure 3 shows the temperature variation observed in the back of the male participants in both cases using (a) stationary Bike A. At the start of the test, participants adjusted the seat height and handlebar height of the stationary bike according to their physical characteristics.

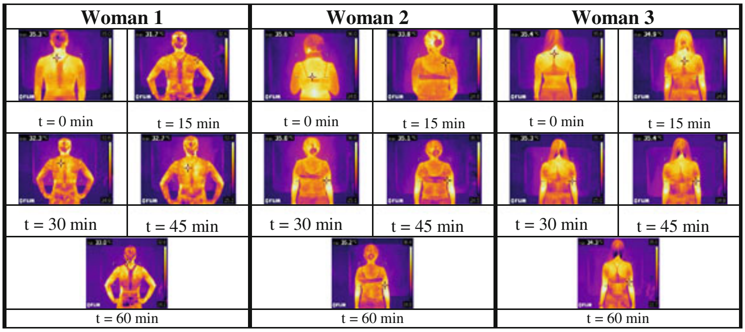


Fig. 2 Thermal imaging of the female participants using bike A

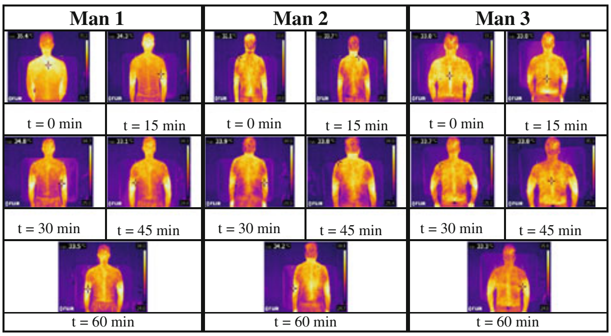


Fig. 3 Thermal images of male participants a bike A

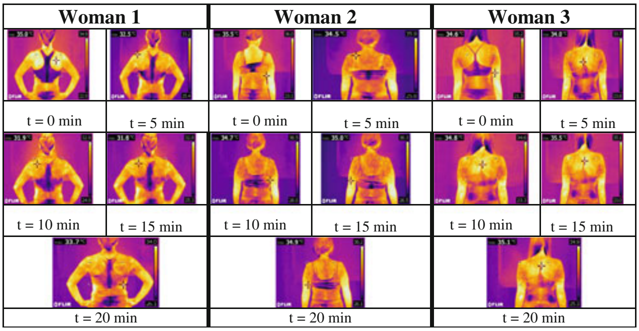


Fig. 4 Thermal imaging of the female participants using bike B

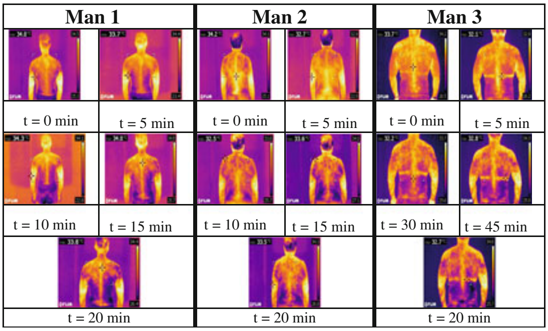


Fig. 5 Thermal imaging of the male participants using bike B

Figure 4 shows images of the back of the female participants for the second phase of the experiment. Figure 5 shows images of the back of the male participants for the second phase of the experiments. In both cases the static Bike B was used. At the beginning of the session, participants of both genders adjusted the seat height according to their height.

In Fig. 6a, the temperature behavior of female participants is observed. The static-cycling instructor who is more experienced (Woman 1) registered the lower

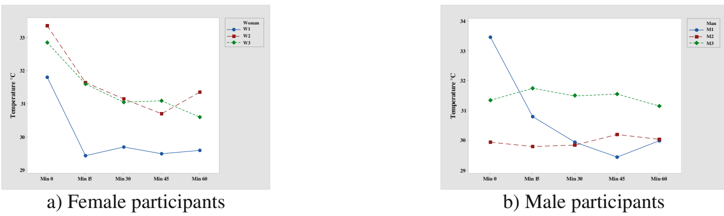
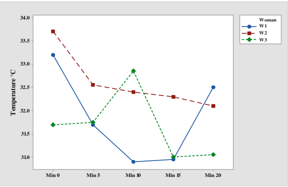
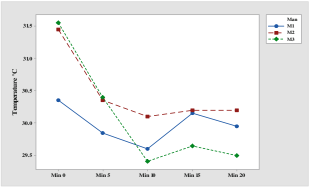


Fig. 6 Temperature behavior for both female and male participants for phase 1 (using bike A). **a** Female participants. **b** Male participants



a) Female participants



b) Male participants

Fig. 7 Temperature behavior for both female and male participants for phase 2 (using bike B). **a** Female participants. **b** Male participants

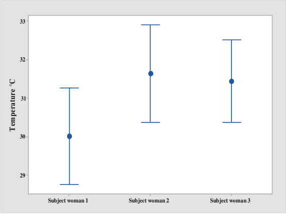
temperature at the end of the experiment (26.2 °C). The participant with less experience in fitness (Woman 2) registered the highest temperature value at the end of the experiment (28.8 °C). In Fig. 6b, the temperature behavior of male participants is observed. The more experienced in static-cycling (Man 1) registered the lower temperature at the end of the experiment (26.3 °C).

Figure 7a, b, shows the temperature behavior observed using Bike B. The capacity of the body to dissipate temperature is altered because the physical effort is controlled.

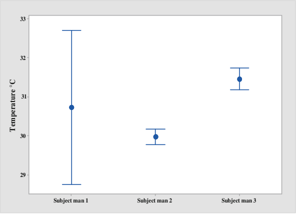
4 Discussion

Today, cycling is gaining more popularity as a recreational sport, as a fitness activity, and even many governments in many countries have promoted cycling as means for transportation. Static-cycling has become an option to improve personal health [11].

Figure 8 shows the graph of temperature ranges at the back of both genders. It is observed temperature ranges close to 2 °C. Similar behavior can be observed in the female participants. For the male participants, one of them (man 1) registered the highest temperature thermoregulation capacity. Diet daily control and continuous exercise is observed with this participant as well as in woman 1. Metabolic response is related to body heat generation [7].



a) Female participants



b) Male participants

Fig. 8 Temperature ranges of female and male participants for phase 1 (using bike A). **a** Female participants. **b** Male participants

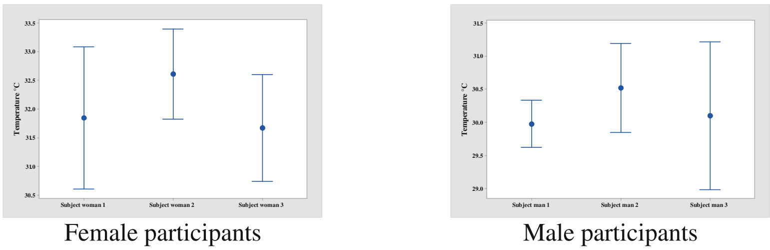


Fig. 9 Temperature ranges of female and male participants for phase 2 (using bike B). **a** Female participants. **b** Male participants

A decrement in skin temperature after exercise is observed because of prolonged action of sweating during dynamic exercise. It is known that after exercise one of the responses of the vascular system is the redistribution of blood flow (Fig. 9).

Posture and adequate pedaling techniques are important factors to avoid discomfort in the back, pain or musculoskeletal injuries. Practitioners have reported back pain after several days of hard training. This pain can be produced by several factors like excess in the pedaling load, keeping a curved spine position, wrong horizontal or vertical adjustment of the seat, wrong pedaling technique, bouncing during pedaling, short resting periods, short muscle recovery lapses, and wrong feeding among others. When this kind of injury is present, it can last for several days. Professional static-cycling instructors have adequate knowledge for adjusting the bike seat according to body size and to have an adequate work station.

Similarities between athletes and musicians have been previously recognized. Musicians are known as musical athletes, both have in common that they begin to practice at an early age, both require a high level of skill and physical ability to practice for several hours. Therefore, they are exposed to developing skeletal muscle disorders [11, 12]. Sports and recreational activities currently are becoming occupational activities for which it is necessary to develop appropriate work stations to prevent skeletal muscle injury because they practice for long periods of time to achieve a high levels of performance.

The methodology used in this study can be applied to carry out the ergonomic analysis of seats for different employees at different workstations as in the case of musicians, drummers, cyclists, athletes or in the industrial sector.

5 Conclusions

In this work, a series of thermographic images were taken to a group of women and men during a practice of static-cycling. The back of the participants was the main observation subject. Participants with a better physical condition showed to have a better capacity to reduce their body heat with respect to non-experienced. Infrared thermography can help to identify risk factors for musculoskeletal injuries for workers that spend many hours sitting, like cyclists and drummers, they constantly use their upper and lower extremities and the back receives these mechanical loads. Future areas of research using infrared thermography can help to improve in seats, breaks or resting periods, working stations and for example in the redesign of seats for people with disabilities allowing them to have an opportunity to participate in working or sporting fields.

Acknowledgments Authors acknowledge the National Council of Science and Technology (CONACYT), the National Polytechnic Institute (IPN) of Mexico and special thanks to professional trainer Wendy Gastelum and also Omar Cisneros, Rubi Torres, Jesús Rodriguez, Oscar Sotelo and Samahara Soto for the support provided in the development of this academic research.

References

1. Bartuzi, P., Roman-Liu, D., Wiśniewski, T.: The influence of fatigue on muscle tem-perature. Int. J. Occup. Saf. Ergon. **18**, 233–243 (2012)
2. Yoguez, A., Gutiérrez, C.C., López, M.A., Jiménez, J.A.: Estudio preliminar de la evaluación de riesgos músculo esqueléticos a través de la termografía infrarroja en una célula experimental de montaje. Organización y Dirección de Empresas, Estudios Industriales. **88**, 704–710 (2013)
3. Oser, S.M., Oser, T.K., Silvis, M.l.: Evaluation treatment of biking and running injuries. Prim Care. **40**, 969–986 (2013)
4. Zaïdi, H., Taïar, R., Fohanno, S., Polidori, G.: The influence of swimming type on the skin-temperature maps of a competitive swimmer from infrared thermography. Acta Bioeng. Biomech. **9**, 47–51 (2001)
5. Priego, J.I., Carpes, F.P., Bini, R.R., Salvador, R., Pérez, P., Cibrián, R.S.: Relationship between skin temperature and muscle activation during incremental cycle exercise. J. Therm. Biol. **48**, 28–35 (2015)
6. Priego, J.I., Martínez, N., Cibrián, R.M., Psikuta, A., Annaheim, S., Michel, R., Corberán, J.M., Pérez, P., Salvador, R.: Effect of perspiration on skin temperature measurements by infrared thermography and contact thermometry during aerobic cycling. Infrared Phys. Technol. **72**, 68–76 (2015)
7. Chudecka, M., Lubkowska, A.: The use of thermal imaging to evaluate body temperature changes of athletes during training and a study on the impact of physiological and morphological factors on skin temperature. Hum. Mov. **13**, 33–39 (2012)
8. Ayachi, F.S., Dorey, J., Guastavino, C.: Identifying factors of bicycle comfort: an online survey with enthusiast cyclists. Appl Ergon. **46**, 124–136 (2015)
9. Bini, R., Hume, P.A., Croft, J.L.: Effects of bicycle saddle height on knee injury risk and cycling performance. Sports Med. **41**, 463–476 (2011)
10. Roy, R., Boucher, J.P., Comtois, A.S.: Validity of infrared thermal measurements of segmental paraspinal skin surface temperature. J. Manipulative Physiol. Ther. **29**, 150–156 (2006)
11. Flores, B.C., Yoguez, A., Susarrey, O., Gutiérrez, C.C.: Preliminary study on the evaluation of musculoskeletal risks through infrared thermography for drummers. Procedia Manuf. **3**, 4415–4420 (2015)
12. Stanhope, J.: Physical performance and musculoskeletal disorders: are musicians and sports people on a level playing field? Perform. Enhancement Health **4**, 18–26 (2015)

The Effect of Different Protection Level on Pilots' Respiratory and Cardiovascular System

Hongjun Zhao, Hongyu Gu, Xiaopeng Liu, Li Ding and Huiting Qiao

Abstract The continuous positive-pressure ventilation and the pressure suit are the most commonly performed to protect pilot from hypoxia in high altitude flights, which may affect both pilots' respiratory and cardiovascular system. Nevertheless, most studies did not discuss the influence of respiratory system. To investigate the physiological response of high-flight protection when respiratory system and cardiovascular system are both considered, the couple of respiratory mechanics model and multi-unit lumped parameter cardiovascular system model was established. The numerical simulation results demonstrated the significant changes in human respiratory and circulation systems under different protection levels, and the intrapleural pressure increase significantly with the increase of ventilation pressure. The mean arterial pressure (MAP) increase linearly and the cardiac output (CO) decrease with the increase protection level. The model is validated with experimental data on the ground.

Keywords High-altitude protection · Respiratory system · Circulatory system · Numerical simulation

1 Introduction

The low air pressure and hypoxia conditions may occur in high altitude flights, and protection measures are needed [1–3]. When the flight height reaches 12 km, the continuous positive-pressure ventilation of pure oxygen from mouth is essential to

H. Zhao · H. Gu · L. Ding · H. Qiao (✉)
School of Biological Science and Medical Engineering, Beihang University,
Beijing 100191, China
e-mail: 08853@buaa.edu.cn

L. Ding
e-mail: ding1971316@buaa.edu.cn

X. Liu
Institute of Aviation Medicine, Air Force, Beijing 100142, China

M. Soares et al. (eds.), *Advances in Ergonomics Modeling, Usability & Special Populations*, Advances in Intelligent Systems and Computing 486,
DOI 10.1007/978-3-319-41685-4_51

protect pilot from hypoxia [4], meanwhile, the pressure suit is performed to provide the compensatory pressure protection. The ventilation pressure is related to the compensatory pressure, which all based on flight height. These high-flight protection may have a great influence on pilots' cardiovascular and respiratory system [5].

Some researches has been focused on the influence of the cardiovascular system of the high-flight protection [6, 7]. The human cardiovascular system is a complex physiology system, and mathematical models are powerful tools for understanding and investigating complex systems [8]. The models of cardiovascular system have been established to simulate cardiovascular responses of different condition, such as Heldt's lumped parameter model [9], Melek's fuzzy logic model [10], and Heusden's [11] lumped circuit model. It is reported that the pressure suit affects cardiovascular system by changing peripheral resistance of blood vessels, and the circulating blood and cardiac output reduced with the increasing the peripheral blood pressure [12]. However, most studies did not discuss the influence of respiratory system. The purpose of this study is to investigate the physiological response of high-flight protection when respiratory system and cardiovascular system are both considered.

In this study, a coupled of respiratory mechanics model and multi-unit lumped parameter cardiovascular system model was established to quantitatively describe the physiological responses of high-flight protection. The model is validated with experimental data. This study may provide a theoretical support for the design and optimization of the flight safety equipment.

2 Methods

2.1 Experimental Description

Subject

The experiment data were collected from 5 males (18–23 years old) with an average height of 170 cm and an average weight of 70 kg. All subjects are healthy and have no history of cardiovascular or respiratory disease. Written informed consent was obtained from all participants. The study was approved by the Ethics Committee of Biological Science and Medical Engineering School in Beihang University.

Experiment Protocol

Each subject wore the pressure suit and mask which providing continuous positive-pressure ventilation of pure oxygen from mouth. Prior to the experiment, all the subjects were trained to master the skills needed for pressurized breathing. In each individual experiment, the protection pressure were pressurized at 4 different levels, including 0, 20, 40 and 60 cm H_2O. At each level, the pressing process lasted 3 min for each test.

(A) (B)

Fig. 1 Experimental apparatus. The physiological parameter were recorded by Portapres® (**a**), the BeatScope® software (**b**)

Experimental Apparatus

The physiological parameter were recorded by Portapres® [13], and heart rate (HR), mean arterial pressure (MAP), stroke volume (SV), cardiac output (CO) and total peripheral resistance (TPR) were calculated by BeatScope® [14] software, as shown in Fig. 1.

Data analysis

Statistical analysis was accomplished using a multivariate software package (SPSS 20.0) with a significance level of $p < 0.05$ throughout and the results were displayed in the form of the mean value ± the standard deviation ($\bar{x} \pm s$).

2.2 Model Description

Model structure

In this study, a multi-unit lumped parameter model of cardiovascular system and a respiratory mechanics model were established independently, and then the couple model was realized by intrapleural pressure.

(i) The multi-unit lumped parameter model as shown in Fig. 2a describes cardiovascular system, which containing pulmonary and systemic circulations. Where *P*th is the intrapleural pressure, *pa* is the pulmonary artery, *pv* is the pulmonary vein, *l* represents the left, *r* represents the right, *a* is the aorta, *sp* is the abdomen, *up* is the upper limbs, *ll* is the lower limbs, *sup* is the superior vena, and *inf* is the inferior vena cava. And in this model, the effects of pressure suit were simulated by the variation of resistance of some sensitive unit.

(ii) As shown in Fig. 2b, a respiratory mechanics model was established, including continuous positive-pressure ventilation module and respiratory mechanics module.

Where *Pd* represents the sources of the continuous positive-pressure ventilation of pure oxygen, *Pmus* represents the work of respiratory muscles, *Rt* is

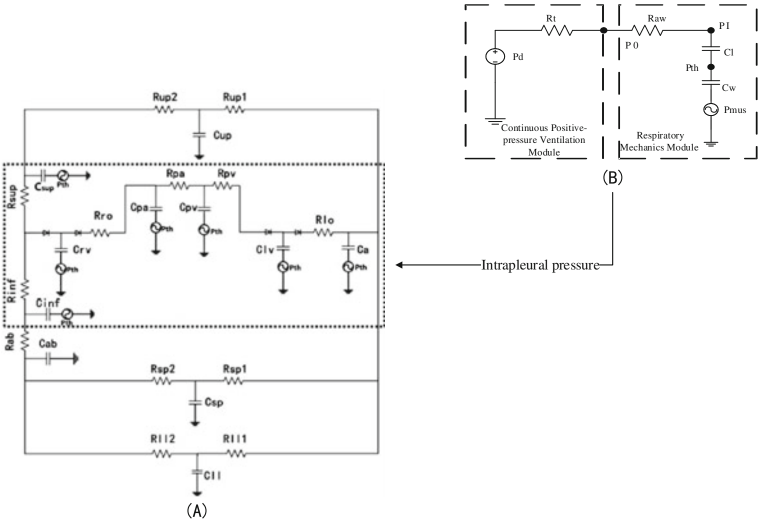


Fig. 2 The couple model of respiratory system and cardiovascular system. Effective coupling is realized by intrapleural pressure between the multi-unit lumped parameter model of cardiovascular system (**a**) and the respiratory mechanics (**b**)

the represent system resistance, *Raw* is the airways resistance, *Cw* is the chest wall compliance, *Cl* is the lung compliance, *P0* is the mouth pressure, *P1* is the intrapulmonary pressure, and *P*th represents the intrapleural pressure.

(iii) A couple of respiratory system and cardiovascular system was realized by intrapleural pressure.

Parameters and Simulation

The model parameters were determined by experiment data on group. The heart rate was estimated by the regression equation with pressure, which is obtained from the experiment data. It is needed to note that the intrapleural pressure in the model of only cardiovascular system is a standard value, while in the couple model the intrapleural pressure is achieved from the respiratory mechanics model. The physiological responses of these model, such as MAP, CO and SV were compared with experiment data.

3 Results

3.1 The Experimental Results

Table 1 shows the hemodynamic conditions include MAP, TPR, HR, SV and CO under different pressures. It is clear that the MAP, TPR and HR increase

Table 1 The hemodynamic conditions

Pressure level (cm H_2O)	MAP	TPR	HR	SV	CO
0	96.22 ± 1.59	1.02 ± 0.06	79.67 ± 2.55	70.52 ± 2.28	5.62 ± 0.25
20	123.73 ± 1.76	1.71 ± 0.07	89.68 ± 3.19	58.46 ± 3.85	5.24 ± 0.18
40	137.35 ± 7.23	3.1 ± 0.14	87.70 ± 4.18	44.56 ± 3.85	3.91 ± 0.19
60	149.14 ± 7.63	2.86 ± 0.31	91.40 ± 4.18	41.00 ± 4.23	3.75 ± 0.34

significantly ($p < 0.01$), and SV and CO decrease significantly ($p < 0.01$) after pressurization.

3.2 The Simulation Results

First, the effect of different protection level on pilots' cardiovascular system was acquired by the multi-unit lumped parameter model, and the results showed that the changes of MAP, CO and SV under different pressure level are consistent with experimental data. Figure 3 shows the left ventricular pressure, aortic pressure increase and aortic blood flow decrease with the increasing compensatory pressure.

And then, the respiratory mechanics model successfully predicted the work of breath (WOB) under natural breathing maneuvers and positive-pressure ventilation maneuvers, which are consistent with literature data [15–17]. Figure 4 shows the effect of different protection level on pilots' respiratory system. It is clear that

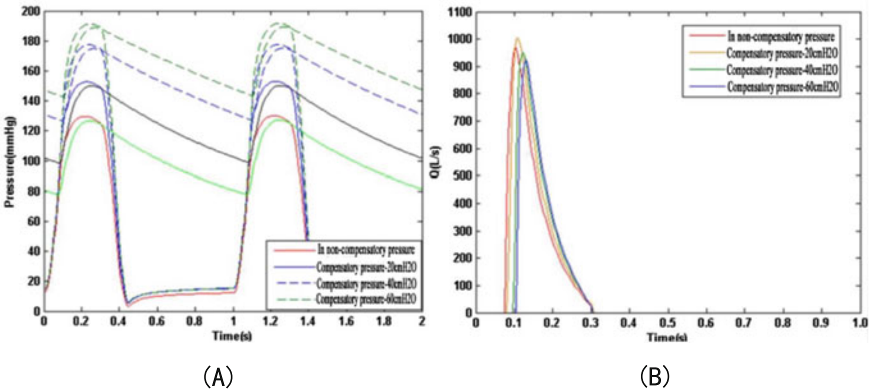


Fig. 3 The results of cardiovascular system model under different compensatory pressure. The *solid line* depicts the left ventricular pressure and the *dotted line* depicts the aortic pressure (**a**), aortic blood flow (**b**)

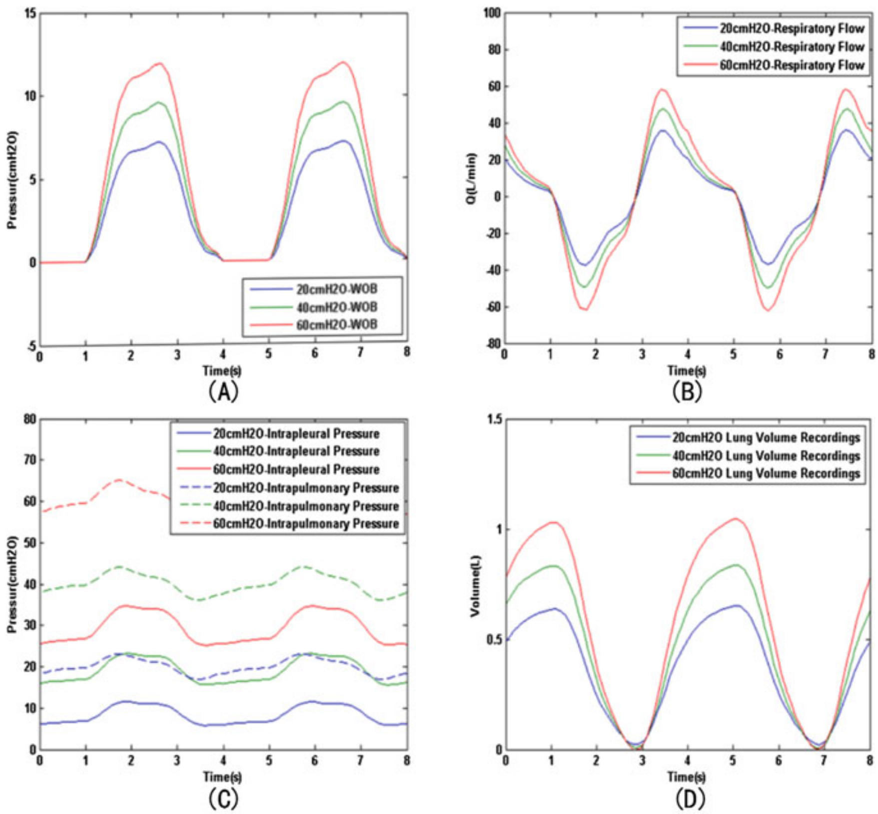


Fig. 4 The results of respiratory mechanics model under three different pressure level. WOB (**a**), respiratory flow (**b**), intrapleural pressure and intrapulmonary pressure (**c**), lung volume recordings (**d**)

the work of breath (WOB), respiratory flow, and tidal volume (TV) increase with the increasing pressure. The intrapleural pressure and intrapulmonary pressure increase linearly with the increase protection level.

At last, we applied the intrapleural pressure from the respiratory mechanics model to the circulation systems, and the numerical simulation results of the couple model successfully demonstrated the significant changes in human respiratory and circulation systems under different protection levels. The results also showed that the intrapleural pressure increase significantly with the increase of ventilation pressure (Fig. 5).

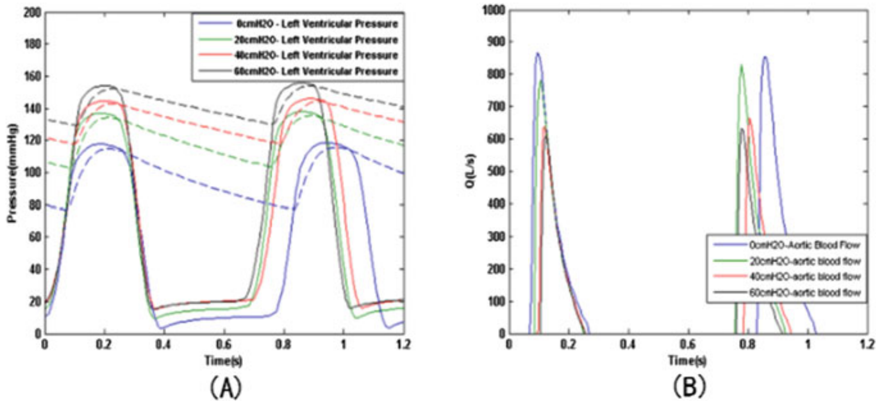


Fig. 5 The results of the couple model under different protection level. The *solid line* depicts the left ventricular pressure and the *dotted line* depicts the aortic pressure (**a**), aortic blood flow (**b**)

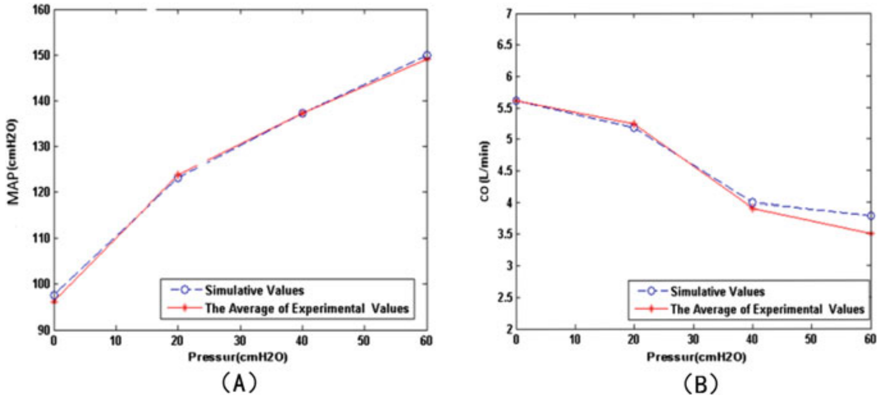


Fig. 6 Comparative chart of simulative and experimental MPA (**a**) and CO (**b**) values under different pressure

4 Discussion and Conclusions

The model was validated with experiment date as show in Fig. 6. The MAP increase linearly and the CO decrease with the increasing protection level.

In conclusion, the respiratory system do have influence on the cardiovascular system during high-altitude protection, and this effect is produced by intrapleural pressure. This coupled model could describe the physiological responses of high-flight protection when respiratory system and cardiovascular system are both considered. This study may provide a theoretical support for the design and optimization of the flight safety equipment.

References

1. Pickard, B.J.: Altitude decompression sickness in a pilot wearing a pressure suit above 70,000 feet. Aviat. Space Environ. Med. **74**, 357–359 (2003)
2. Rudnjanin, S., Rudnjanin, S., Rudnjanin, S., Arsic-Komljenovic, G., Arsic-Komljenovic, G., Arsic-Komljenovic, G., et al.: Loss of consciousness as criterion of +Gz tolerance at Institute of Aviation Medicine MMA during +Gz acceleration selective test. Acta Physiol. Hung. **93**, 371–376 (2006)
3. Murray, D.H., Pilmanis, A.A., Blue, R.S., Pattarini, J.M., Law, J., Bayne, C.G., et al.: Pathophysiology, prevention, and treatment of ebullism. Aviat. Space Environ. Med. **84**, 89–96 (2013)
4. Bardel, M., Bloch, N., Martinez, P.: Individual Respiratory Gas Supply Device Including a Respiratory Mask and a Facial Respirator (Google Patents, ed.) (2005)
5. Yang, T., Ding, L., Zhang, C., Qin, Z.: Hemodynamic simulation of partial pressure suits under pressure. J. Beijing Univ. Aeronaut. Astronaut. **8**, 025 (2013)
6. Liang, F., Senzaki, H., Kurishima, C., Sughimoto, K., Inuzuka, R., Liu, H.: Hemodynamic performance of the Fontan circulation compared with a normal biventricular circulation: a computational model study. Am. J. Physiol. Heart Circ. Physiol. **307**, H1056–H1072 (2014)
7. Blanco, P., Feijóo, R.: A dimensionally-heterogeneous closed-loop model for the cardiovascular system and its applications. Med. Eng. Phys. **35**, 652–667 (2013)
8. Leaning, M., Pullen, H., Carson, E., Finkelstein, L.: Modelling a complex biological system: the human cardiovascular system—1. Methodology and model description. Trans. Inst. Measur. Control **5**, 71–86 (1983)
9. Heldt, T., Shim, E.B., Kamm, R.D., Mark, R.G.: Computational modeling of cardiovascular response to orthostatic stress. J. Appl. Physiol. **92**, 1239–1254 (2002)
10. Melek, W.W., Lu, Z., Kapps, A., Cheung, B.: Modeling of dynamic cardiovascular responses during G-transition-induced orthostatic stress in pitch and roll rotations. IEEE Trans. Biomed. Eng. **49**, 1481–1490 (2002)
11. van Heusden, K., Gisolf, J., Stok, W.J., Dijkstra, S., Karemaker, J.M.: Mathematical modeling of gravitational effects on the circulation: importance of the time course of venous pooling and blood volume changes in the lungs. Am. J. Physiol. Heart Circ. Physiol. **291**, H2152–H2165 (2006)
12. Huajun, X.: Physiology of Aviation Oxygen Protective Equipment. Military Medicine Science Press, Beijing (2005)
13. Hu, H., Ding, L., Hedge, A., Li, X., Zhang, C., Qin, Z., et al.: The effects of pressurized partial pressure suits on operational ergonomics. Int. J. Ind. Ergon. **45**, 107–115 (2015)
14. Li, X., Ding, L., Hedge, A., Hu, H., Qin, Z., Zhou, Q.: An experimental study on the ergonomics indices of partial pressure suits. Appl. Ergon. **44**, 393–403 (2013)
15. Borg, B.M., Thompson, B.R., O'Hehir, R.E.: Tests of respiratory muscle strength. In: Interpreting Lung Function Tests: A Step-by-Step Guide, pp. 79–98 (2014)
16. Yu, C.-H., Su, P.-L., Lin, W.-C., Lin, S.-H., Chen, C.-W.: Simulation of late inspiratory rise in airway pressure during pressure support ventilation. Respir. Care **60**, 201–209 (2015)
17. Borrello, M.: Modeling and control of systems for critical care ventilation. In: Proceedings of the 2005 American Control Conference, pp. 2166–2180 (2005)

Requirements' Elicitation for a Tangible Interface-Based Educational Application for Visually Impaired Children

Asma Alhussayen, Rabia Jafri and Abir Benabid

Abstract Tangible user interfaces (TUIs) have great potential to provide visually impaired (VI) students with educational software that is both accessible and appealing. To ensure the usability of such software, the special needs of the target users should be considered throughout its design; hence, a user centered design (UCD) approach is required. The aim of this study was to conduct user research to elicit requirements for an assistive TUI-based educational software solution for VI students in Saudi Arabia. The local education context was explored through field observations and semi-structured interviews with special education teachers at an inclusive public elementary school that offered special education classes for VI students. Findings from the study have revealed that tangibles are an indispensable part of current teaching practices, established the teachers' willingness to use TUI-based software solutions and uncovered a need for a fun and engaging software for VI students to practice and grasp mathematical concepts.

Keywords Tangible user interface · User centered design · Visually impaired children · Educational application · Blind · Requirements' elicitation

1 Introduction

Educational software has enhanced the learning experience for students and provided them access to ample information resources. According to [1], computer software and Internet access are of high importance for people with visual

A. Alhussayen (✉) · A. Benabid
Department of Software Engineering, King Saud University, Riyadh, Saudi Arabia
e-mail: aalhussayen@ksu.edu.sa

A. Benabid
e-mail: abbenabid@ksu.edu.sa

R. Jafri
Department of Information Technology, King Saud University, Riyadh, Saudi Arabia
e-mail: rabia.ksu@gmail.com

M. Soares et al. (eds.), *Advances in Ergonomics Modeling, Usability & Special Populations*, Advances in Intelligent Systems and Computing 486,
DOI 10.1007/978-3-319-41685-4_52

impairment as well to gain information. However, the use of technology for educational purposes for visually impaired (VI) students, specifically young children, is limited due to the visual representation of information in computer applications and unsuitable interaction means. Available assistive technologies for accessing information include screen readers, voice synthesizers, magnifying software, Braille devices (printer and Braille display) and text recognition applications. In a survey performed to identify the assistive technologies used by VI students for learning, only 50 % of the students were reported using assistive technologies and computers for educational purposes [2]. This, as reported in the study, is mainly a result of the teachers' inadequate training to use the available technologies.

When a student is VI, it is necessary to provide tangible materials to touch, explore and interact with in order to gain conceptual understanding of presented information. Using physical objects has proven to be useful in general in children's development, as Montessori et al. [3] believed that young children's play with physical objects enabled them to engage in self-directed, purposeful activity. Tangible User Interfaces (TUIs) provide users with new and creative means of interaction different than the accustomed-to interaction in GUIs and more suitable for the VI users. Ulmer [4] defined TUIs as "a genre of human-computer interaction that uses spatially reconfigurable physical objects as representations and controls for digital information". Using a TUI-based application, users interact with the application through manipulating and examining physical objects and receiving feedback accordingly. Studies, such as [5, 6], have shown that tangibles provide new methods for VI children to learn, through unique ways of interaction and the ability to add playfulness and enjoyment to learning. Also, teaching VI children basic concepts relies heavily on examining and touching real objects. TUI based applications, therefore, present an appropriate educational tool to promote learning.

With children users, it is crucial to gain knowledge of their mental and psychomotor development, as well as understanding their needs, desires and expectations with regard to the kind of product designers are working on [7]. The complexity of designing user interfaces for children becomes much greater when the child is visually impaired. To design a software interface that successfully meets their needs, the design must be user-centered from conceptualization up to the software evaluation. Designing a TUI-based application poses a new challenge for design and Human Computer Interaction (HCI) as they require the design of the digital, the physical, and their interrelations. Also, the ease of interaction in a TUI-based application has an influence on the user experience and must be designed according to the VI students capabilities. Therefor, a user-centered design approach must be followed that takes into account the needs and capabilities of the special target users from the early phases of the design. The objectives of this research are as follows:

- Identify the educational practices and technologies that are being used in the education of VI students (ages 7–9) in the local context: Saudi Arabia to elicit the user requirements.

- Design a TUI application taking into account the children's needs, related to level of visual impairment and psychological development, all along the design process.
- Evaluate the usability and the user experience of the TUI application to ensure reliable delivery to the target users' population (VI children) with acceptable levels of effectiveness, efficiency and satisfaction.

The study reported in this paper is focused on fulfilling the first objective stated above through conducting a field observation of the local educational context followed by semi-structured interviews for gathering user needs. The rest of the paper is organized as follows: First, a review of related work in designing educational applications for VI students is presented in Sect. 2. Then, details of the study including the field observation of VI students in their classroom and semi-structured interviews with special education teachers for eliciting requirements are described in Sect. 3. Finally, the paper concludes by reporting design recommendations and future work in Sect. 4.

2 Related Work

The qualities of TUIs and the unique types of interactions they provide have attracted researchers to this new field of study. Development of TUI-based educational applications for VI people in particular has gained considerable interest and dedicated TUI-based educational applications have been designed in [8–11]. McGookin et al. [8] investigated the capability of TUIs for providing non-visual access to graphs to VI users. VI users successfully created and explored graphs during the evaluation of the system. Other systems were designed for classroom use, such as the study presented in [9], where researchers developed the Trackable Interactive Multimodal Manipulatives (TIMMs) that allow VI students to independently learn educational concepts through interacting with digital manipulatives. However it requires configuration of the software by the classroom teacher. Also, a TUI-based spatial application is designed to teach VI children tactual shape perception and spatial relationship concepts in [10]. The goal was to provide VI children teachers with a low-cost do-it-yourself system by utilizing off-the-shelf components for setting up the TUI, using 3D printing for generating the tangible tokens and employing the open source system Trackmate [12] for tracking the tokens. Another study presented in [11] proposes a software solution for teaching Braille letters to young VI children. Tangible interaction is offered through manipulating NFC tag-embedded blocks with Braille letters embossed on their sides. In addition to the tangible feature, learning with the blocks is effortless and clear for very young children and does not require any computing experience. The proposed software is low in cost and encourages collaboration activities.

An important part of designing TUI-based applications is the process of understanding and gathering user requirements, which was not described in the studies stated above. Designers have involved children in the design process of technology using Druin's four levels [13] of child involvement in the design process: users, testers, informants, or design partners. An example of including children as informants are the Informant Design workshop sessions conducted with children aged nine and ten years in [14]. The method was applied to understand and gather requirements from the children for designing a TUI-based museum learning environment. In the sessions, the researchers explained the basic idea of the device and asked the children to list the functionalities they expected. Then they asked the children to draw a design for the device and make the physical device using paper and craft. Finally, to demonstrate the functionality of their devices, children acted out with their devices. The sessions were supervised and documented with pictures and notes and the researchers found the informant design method useful for understanding children need and preferences and for elaborating early design ideas. As for VI children, Guha et al. [15] investigated including children with special needs in the design process and described an inclusionary model for designing for children with special needs. The study reported that VI children could be involved as design partners especially when the support of a special education aide is available. In this study, VI children are involved as informants [13] through observing their behaviors and learning activities in the classroom.

A well-known approach for gathering user needs that can be applied in the early phases of a UCD process is the Cooperative Inquiry of Druin [16], which includes principles of Participatory Design customized to be suitable for designing with children. Some researchers employed the Cooperative Inquiry approach by including children in the design process of a TUI-based software as design partners such as the studies described in [7, 17]. Researchers in [7] designed NIKVision, a set of TUI-based games for young children and children with special needs. The children were actively involved from the beginning of the conceptual stage of the design process. Variations in the children's needs and social skills have been considered in the design of the system through observing the children in their environment to originate new suitable concepts of tangible applications then using the Wizard of Oz Prototyping method to determine specifications of the concept game. Prototyping with physical interaction includes prototyping the graphical interface as well as gesture recognition. Although this game was evaluated with children with special needs, it was not designed with them and the children involved in the design were with typical abilities. On the other hand, the researchers in [17] have involved VI children (ages 3–12) as co-designers in integrating the audio and tactile sensory experience into the design process of toys and computer games. In the study, the researchers developed three prototypes of three different game and play scenarios with the children's involvement. This study was conducted as part of a long-term project that focused on designing better games for the VI children

This Approach to research is powerful for understanding the characteristics and needs of children with special needs as users. However, it is very challenging to apply in practice. In fact, in practice, intensively involving VI children in the design might raise some problems such as how to get the right kind of input from users especially if they are young children, and then often requires from the designers to balance conflicting demands. Moreover, other problems can be encountered in this approach such as getting the consent, or having limited budget while this approach requires a considerable length of time and resources. With the limited time and resources available to us, we applied two methods for gathering user requirements: (a) Field Observation and (b) Semi-structured interviews with special education teachers.

3 Requirements Gathering Procedure

This section describes the methods used to gather and elicit requirements for designing an educational TUI-based solution for VI students of ages (7–9) in Saudi Arabia. To gain an understanding of the local education environment, consent was obtained from a public inclusive-school for girls in Riyadh, Saudi Arabia to conduct field observation of the VI students in their special education classes followed by semi-structured interviews with their special education teachers. The school includes VI students in regular classes and offers the 1st, 2nd and 3rd grade students (ages 7–9) special education classes to learn reading and writing in Braille and learn mathematical principles.

3.1 Field Observation

The objective of the field observation was to observe the VI students in their classes while paying special attention to the learning environment and the use of tangibles or any computer-based software. The study was conducted during one school day for the 1st grade class and three teaching sessions were observed. Inside the class, detailed notes were taken of the teaching process and the activities. Also, photos were taken of the teaching materials as well as the students' interaction with them

3.1.1 The Setting

The teacher sat at the head of a Copenhagen group table and four students sat around the table. One student with residual vision had a learning disability and was 3 years older than her classmates. Only one student was completely blind while the others had residual vision. The classroom also included a table with four Braille typewriters and a cabinet for the teaching tools, which were: Braille Teacher boards, braille typewriters and Cubarithm Slate shown in Fig. 1. The classroom was colorful, however, the teaching tools were not- they were colored in light grey, dark grey and brown.

Fig. 1 Teaching tools: **a** Braille teacher board, **b** Typewriters and **c** Cubarithm slate

3.1.2 Teaching Sessions

The special education sessions were limited to three subjects: reading, writing and mathematics. Each session was 45 min long and the following were observed:

- In the mathematics and writing lessons, the students were writing using the braille teacher board. The process of writing on the braille teacher board required students to click on the 6 dot pins in each cell (10 cells were provided in the board) to change them between lower state and raised state in order to represent the desired letter or number as shown in the close-up image in Fig. 1a. This process was slow as students were only able to practice seven words and solved five subtraction exercises in mathematics session.
- The students also practiced writing mathematical operations using the Cubarithm Slate. The cubes have a number in braille embossed on each side and students placed them in the slate to represent arithmetic problems where each cube represents one digit. The cubes were very small (1″ × 1″) and required practice to rotate them to find the desired digit.
- In the reading lesson, students were reading from their Braille books and did not use any assistive material.
- The student with learning disability required more attention from the teacher and the remaining students appeared to be bored while waiting and also interrupted the teacher numerous times while she was assisting the student with the learning disability.
- The teacher rewarded students with 3D stickers, which they chose by touching and feeling the stickers and seemed to favor the largest sticker available. Students with residual vision also appeared to favor the color Fuchsia.

3.1.3 Discussion

The aim of the field observation was to gain insight into the local learning environment for the VI students of ages (7–9), identify the usage of any educational assistive devices and uncover any difficulties experienced by the students and the teachers in the current learning environment. The organization of the classroom and the seating around the Copenhagen table was useful for keeping the teacher aware of the students' activities at all time. This was particularly important because the teacher's feedback was required constantly for each student. The existence of a student with learning difficulty seemed to slow down the progress in class since she retained more attention from the teacher while the other students were waiting. This was evident in the writing and mathematics sessions when the learning disability student needed the teacher's assistance to complete her tasks correctly. However, in the reading lesson, the student with learning disability was not present since she went for her own special education class, and then the students progressed at a faster pace than they did in the writing and mathematics lessons.

The tangibles used in class are limited to the materials described above which are means of presentation only without giving any feedback or assistance for the students in any way. Writing with the Braille Teacher board, in both writing lesson and mathematics, seems cumbersome since the student has to make sure that the correct pins are raised and the others are in a lower state. The limited number of cells (only 10 cells) makes the board usable for short words and short mathematical operations only. While the Cubarithm Slate allowed for presenting longer mathematical operations, it was difficult to work with and required practice to handle the cubes.

These observations of the current learning environment highlight the extensive use of tangibles in the learning activities and the absence of assistive technology in the teaching practices. This suggests the need for educational applications able to provide feedback and evaluate the student's performance. Providing such applications in class will offer the teacher more time for assisting students with learning difficulties while the other students would be interacting with the application.

3.2 *Semi-structured Interviews*

Semi-structured interview questions were prepared for the purpose of collecting information related to the current teaching practices, the challenges faced in teaching basic concepts and the extent of technology use in the classroom. The interview consisted of five parts: (a) demographic information of the teachers and their students, (b) currently used teaching strategies in the classroom, (c) difficulties and challenges faced in teaching VI students, (d) teachers' and students' experience with technology and computer-based systems and, (e) the possible ways TUI-based software solutions can benefit the education of the VI students.

3.2.1 Participant Recruitment

Participants of the interview were three special education teachers of 1st, 2nd and 3rd grades from the elementary school where the field observation took place. The purpose of the interview was explained, the importance of the participants' opinion as experts in the education of VI students was highlighted and consent forms were signed. The 1st and 2nd grade teachers were both VI and had graduated from "Alnoor" Institute for the blind in Riyadh, Saudi Arabia, then they received a Special Education Bachelor's degree (Visually Impaired track) and have most work experience (9 and 6 years, respectively). The 3rd grade teacher held a Bachelor's degree in special education and had a one-year experience in teaching VI children. The 1st grade teacher was eloquent and well experienced in the education of VI children as she had experience in supervising the implementation of the VI students' education program. Total number of students in all the grades was seven: four 1st grade students, two in 2nd grade and one in 3rd grade. One 1st grade student had a learning disability and another 1st grade student had total vision loss. Five of the students had experience with computer-based technology (playing games on their tablets) and only two had no experience with any such technology.

3.2.2 Procedure

The interviews took place in each teacher's classroom without the presence of the students. The interviews with the 2nd and 3rd teachers were 20 min long while the one with the 1st grade teacher, who had more experience and larger number of students, was 45 min long. One interview was audio recorded (with the participant's consent) and extensive notes were taken of the other interviews. To analyze the results, the audio-recorded interview was fully transcribed and the collected information from all the interviews was compiled and summarized. Consensus between participants was recorded and disagreements were explored and analyzed. The experience of the interviewee was also considered when analyzing the responses. Following is a summarization of the interview results.

3.2.3 Results

The following subsections describe the results obtained from the interviews.

(a) Teaching Techniques

The teaching techniques used in class are based on playing games and repetition for grasping basic concepts. The teachers highlighted the importance of playing games in class for motivating the students to learn and participate. However, the 2nd and 3rd grade teachers can not get their students excited with game play since their students are few in numbers (2 and 1 respectively). Group-work is an important strategy used by the 1st and 2nd grade teachers in class whenever possible. However, the 3rd grade teacher had only one student and, therefore, cannot involve her in group-work.

When asked about the use of tangibles for teaching, all responses were positive but the tangibles used were different. The 1st grade teacher uses the braille teacher board daily and a strategy for distinguishing similar letters through touching and feeling their lips as they pronounce the letters. The 2nd grade teacher uses the French cube boards and different objects that describe the reading material of the day (such as a toy airplane). The 3rd grade teacher uses geometrical shapes in addition to the same tangibles used by the 2nd grade teacher.

Next the teachers were asked about the common behavior of their students. The 1st grade teacher described her students as mostly excited and competitive while the 2nd and 3rd grade teachers thought their students were bored most of the time. The 2nd grade teacher explained: “they are mostly bored because they are few in numbers and have friends back in regular class”. As for the overall student performance, three 1st grade students are on track while the student with learning difficulty is failing. The 2nd and 3rd grade students are a little behind.

(b) Teaching Challenges

To identify the teaching challenges and difficulties, the teachers were asked to rate the factors affecting their performance in teaching on a scale of 1–5 with 1 being “affecting the least” and 5 “affecting the most”. The bar graph shown in Fig. 2 clearly identifies the existence of other accompanying disabilities as the factor with the greatest impact on the teaching performance. This has also been observed during the contextual enquiry where the teacher had spent more time and focus on a student with a learning disability leaving the other students waiting.

(c) Technology Use in Education

The consensus among the teachers was that using computer-based software for education purposes is valuable, and that they were willing to use educational software in class if a training course is provided. When asked about their own experience in including technology in class, all of the teachers reported using tablets to show pictures and play audio files related to the lessons. However, they explained that the available functionalities and interactions offered by tablets are limited and mostly not accessible for the VI people. The 1st grade teacher reported

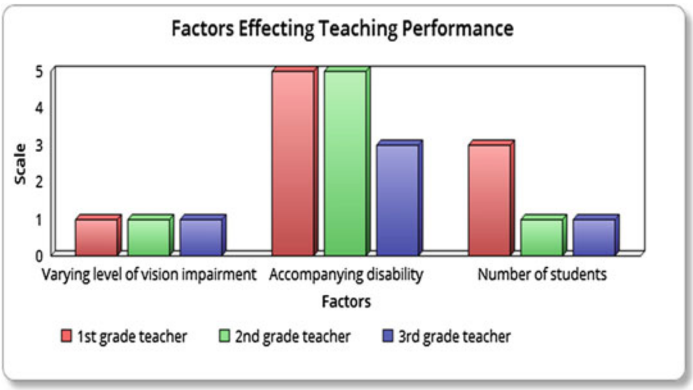


Fig. 2 Factors affecting teaching performance

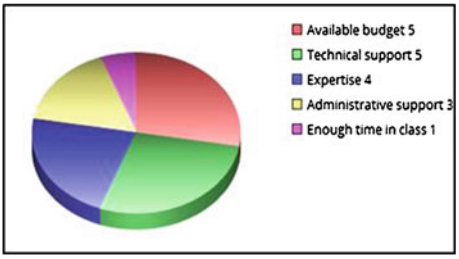


Fig. 3 Factors affecting decision to use technology in class

that the school has provided BrailleNote devices (a digital note taker device) to use in class. Although the BrailleNote provided many functionalities (such as note taking, internet access, text to speech output and braille output), it was deemed too difficult for the students to use, as it was not designed for children. The problem with the device, as the teacher explained, was that it had too many buttons, making it hard for the children to find the functionalities. As a result, it was never used. The teachers were then asked to rate the factors that affect their decision to use technology in class on a scale of 1–5 (with 1 being "least effective" and 5 "most effective"). Figure 3 shows a pie chart representing the average score each factor received. It is clear from the chart that the most affecting factors are the availability of technical support and available budget, followed by having the expertise to use the technical system then the administrative support factor. The least affecting factor was having enough time in class to use technology; the 1st grade teacher commented on that saying, "using a good educational software would actually save time in class".

(d) Proposed Solution

The final section of the interview introduced the idea of tangible interfaces, more specifically the Trackmate tracking system [12], which the application will be built upon. It was explained that the system recognizes and tracks objects placed and manipulated on a tabletop. The teachers were then asked to describe the ways they envision this system used in class. The suggestions included the following: Practice letters and numbers recognition, spelling, math problems and number place value. Most of the suggestions above were related to mathematics, so when asked about the subjects that might benefit the most from such system the responses were in favor of the mathematics subject first then writing followed by reading. To learn about the teachers' expectation on the usability of the system, the usability factors were formulated for understandability in the following way:

- Learnability: Easiness for the students to use after a few tries.
- Accessibility: Support for children's independent interaction, without the teacher's help.
- Satisfaction: Engage the student in fun and exciting learning activities.
- Efficiency and Effectiveness: Perform tasks easily and fast
- Maintainability: Easy to fix and maintain.

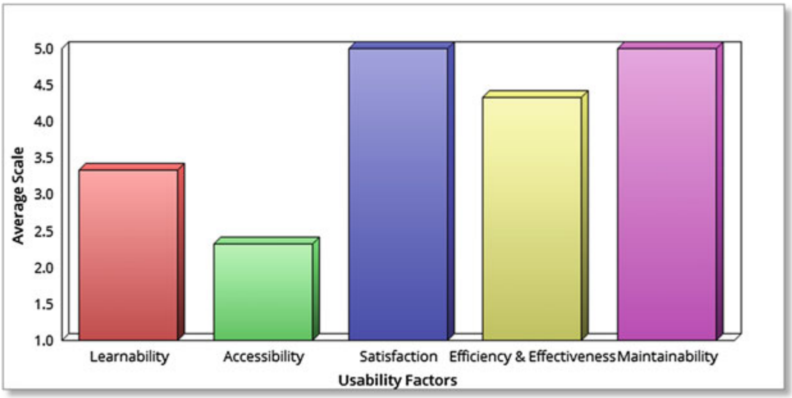


Fig. 4 Scale of the different usability factors

Figure 4 is a bar graph representation of the average score each usability factor received when asked by the teachers to rate on a scale of 1–5 (with 1 being "least important" and 5 "most important"). As the graph shows, the teachers scaled maintainability and satisfaction as the most important factors followed by efficiency and effectiveness then learnability and finally the least important is accessibility which received an average scale of 2.3.

Finally, the design of the tangible objects used for the interaction was discussed regarding the type of material, texture, the size and color of the object. For the material type, two teachers agreed to use cork; a teacher explained that it would be the most suitable since it is cheap, light in weight and easy to replace if damaged. The teachers also agreed that bright colors (for the students with residual vision to see and distinguish) and rough texture should be used. Two teachers described the suitable size to be medium such that it fits in the students' hands while the third teacher was more specific and reported that a 4×6 cork block is an appropriate size for the students to handle.

3.2.4 Design Implications

The aim of carrying out the interviews was to get an insight into the teachers' perception of technology use for educational purposes and to understand the current challenges in the education of VI students. The teachers have identified the existence of students with accompanying disability as the most impacting factor on their performance. The reason behind this, as understood from the teachers, was that these students require more time and attention to follow up with their classmates and therefore hold back the class from progressing faster. A solution to this problem would be to provide an educational application to supplement and enhance learned concepts. This type of application would offer the teachers the time they need to spend with a falling behind student while the other students would be using the software.

The teachers have also agreed on the importance of games and teamwork for capturing the students' attention and keeping them engaged and competitive. But, teachers with a classroom of only 2 or 1 students are unable to involve their students in such engaging activities. For this reason, the software should be designed to offer fun and engagement through game play and support for collaborative learning. In addition, the teachers have identified repetition as an important strategy for memorizing and grasping new concepts. Therefore, this strategy will be employed in the design of the software.

From the teachers' previous experience with using technology for education, they were unsatisfied with the limited functionalities (play audio files and display images), limited interactions and difficult user interface. The TUI will provide a way of interaction suitable for the VI students and ease of reaching functionalities and completing tasks will be considered in the design of the educational application.

As for the subject area of the educational application, the consensus between the teachers is that mathematics will be the most suitable for the application to provide practice on its concepts. Learning word spelling was also suggested by all the teachers, however the 1st grade teacher remarked that it may be useful for the 1st grade students more than the 2nd and 3rd grade students because the older students are required to write whole paragraphs unlike the 1st grade students who write single words. Thus the application will be designed to provide practice on mathematical concepts such as number place value and number calculations. Students will solve mathematical problems through placing braille cork blocks representing numbers and operation signs on a tabletop. The effectiveness of manipulating tangible objects in supporting children's learning as reported in literature will enhance VI students' mathematical skills.

4 Conclusion and Future Work

In this study, the VI user's needs and requirements were gathered for the design and development of a TUI-based educational application to enhance the learning of VI students of ages 7–9 through observing the local learning environment and conducting semi-structured interviews with the teachers of VI children. It was observed that tangible materials are used extensively in class for learning concepts. Findings also identified the absence of assistive technology in class and the presence of children with accompanying disabilities as factors that impact the progress of VI children's education. The teachers also identified mathematics as the subject area appropriate for a TUI-based application and showed interest in using assistive technology in the teaching process. These finding highlight the need for an engaging TUI-based educational application for VI students to individually or collaboratively use in class.

Requirements gathered in this study will be used to design and develop a TUI-based educational application for practicing mathematical concepts. Also, to ensure user satisfaction of the developed application, an evaluation of the usability and user experience will be conducted to understand the user's perception of the application and to provide guidelines for designing an exceptional user experience for VI children.

References

1. Gerber, E.: The benefits of and barriers to computer use for individuals who are visually impaired. J. Vis. Impair. Blind. **97** (2003)
2. Abner, G., Lahm, E.: Implementation of assistive technology with students who are visually impaired: teachers' readiness. J. Vis. Impair. Blind. (JVIB) **96**(02) (2002)
3. Montessori, M., George, A.E., Holmes, H.W.: The Montessori method. Scientific pedagogy as applied to child education in "the children's houses," with additions and revisions by the author. Translated from the Italian by Anne E. George. With an introduction by Professor Henry W. Holmes. With thirty-two illustrations from photographs. New York
4. Ullmer, B.A.: Tangible interfaces for manipulating aggregates of digital information. Doctoral dissertation, Massachusetts Institute of Technology (2002)
5. Juan, C., Canu, R., Gimenez, M.: Augmented reality interactive storytelling systems using tangible cubes for edutainment. In: Eighth IEEE International Conference on Advanced Learning Technologies, 2008. ICALT'08, pp. 233–235. IEEE (2008)
6. Zajc, M., Starcic, A.I.: Potentials of the tangible user interface (TUI) in enhancing inclusion of people with special needs in the ICT-assisted learning and e-accessibility. In: Agent and Multi-agent Systems. Technologies and Applications, pp. 261–270. Springer, Berlin (2012)
7. Cerezo, E., Marco, J., Baldassarri, S.: Hybrid games: designing tangible interfaces for very young children and children with special needs. In: More Playful User Interfaces, pp. 17–48. Springer, Singapore (2015)
8. McGookin, D., Robertson, E., Brewster, S.: Clutching at straws: using tangible interaction to provide non-visual access to graphs. In: Proceedings of the SIGCHI Conference on Human Factors in Computing Systems, pp. 1715–1724. ACM (2010)
9. Manshad, M.S., Pontelli, E., Manshad, S.J.: Trackable interactive multimodal manipulatives: towards a tangible user environment for the blind, pp. 664–671. Springer, Berlin (2012)
10. Jafri, R., Aljuhani M.A., Ali, S.A.: A tangible interface-based application for teaching tactual shape perception and spatial awareness sub-concepts to visually impaired children. In: Proceedings of the 6th International Conference on Applied Human Factors and Ergonomics (AHFE 2015), July 26–30, Las Vegas, Nevada, USA, Elsevier Science Direct Procedia, vol. 3, pp. 5562–5569 (2015)
11. Jafri, R.: Electronic Braille blocks: a tangible interface-based application for teaching Braille letter recognition to very young blind children. In: Proceedings of the 14th International Conference on Computers Helping People with Special Needs (ICCHP 2014), July 9–11, Paris, France, Springer International Publishing, Lecture Notes in Computer Science (LNCS), vol. 8548, pp. 551–558 (2014)
12. Kumpf, A.: Trackmate: large-scale accessibility of tangible user interfaces. Doctoral dissertation, Massachusetts Institute of Technology (2009)
13. Druin, A.: The role of children in the design of new technology. Beha. Inf. Technol. **21**(1), 1–25 (2002)

14. Xu, D., Mazzone, E., MacFarlane, S.: Informant design with children-designing children's tangible technology. In: International Workshop Re-Thinking Technology in Museums, Limerick, Ireland (2005)
15. Guha, M.L., Druin, A., Fails, J.A.: Designing with and for children with special needs: an inclusionary model. In: Proceedings of the 7th International Conference on Interaction Design and Children, pp. 61–64. ACM (2008)
16. Druin, A.: Cooperative inquiry: developing new technologies for children with children. In: Proceedings of the SIGCHI conference on Human Factors in Computing Systems, pp. 592–599. ACM (1999)
17. McElligott, J., Van Leeuwen, L.: Designing sound tools and toys for blind and visually impaired children. In: Proceedings of the 2004 Conference on Interaction Design and Children: Building a Community, pp. 65–72. ACM (2004)

Part VII
Ergonomics Modeling for Industry

Interaction of Haptics, Acoustics and Optics in the Perception of Rotatory Control Devices

Tobias Glohr, Steffen Schynoll, Andreas Zimmermann and Thomas Maier

Abstract Due to a new focus on holistic design and the development of new control devices in cars not only optical features but also haptic and acoustic factors are becoming more important. However, it is necessary to clarify if haptics, acoustics and backlights of controls (optics) are independent factors and can thus be developed separately or if there are interactions between the perceptions of those three modalities. Thus, two independent studies were conducted. The first study investigated the interaction between haptics, acoustics and backlights of controls. Since backlight is not always present while a vehicle is being driven (e.g. insolation during daytime), a second study with a more detailed variation of acoustic and haptic parameters was conducted, omitting optics as a factor.

Keywords Human-Machine interface · Multimodal perception · Control devices

T. Glohr (✉) · T. Maier
Department Industrial Design Engineering, Institute for Engineering Design and Industrial Design University of Stuttgart, Pfaffenwaldring 9, 70569 Stuttgart, Germany
e-mail: tobias.glohr@iktd.uni-stuttgart.de

T. Maier
e-mail: thomas.maier@iktd.uni-stuttgart.de

S. Schynoll · A. Zimmermann
MAN Truck & Bus AG, Engineering Research Electronic Systems, Dachauer Strasse 667, 80995 Munich, Germany
e-mail: steffen.schynoll@man.eu

A. Zimmermann
e-mail: andreas.zimmermann@man.eu

M. Soares et al. (eds.), *Advances in Ergonomics Modeling, Usability & Special Populations*, Advances in Intelligent Systems and Computing 486,
DOI 10.1007/978-3-319-41685-4_53

1 Introduction

Within the vehicle development process the demand for a high-quality interior and unique appearance is rising. The objective is to improve the drivers' well-being and comfort, but also to generate an approach of differentiation between competitors. The human-machine interface provides an opportunity to fulfill these increasing requirements and to realize brand-specific development of a car's interior and its characteristics. In this context particularly new control concepts, e.g. gesture control, are becoming more frequent. But due to the absence of physical feedback in these new concepts [1] conventional controls such as push buttons and knobs are still significant in vehicle development. However, because of the high variety and large number of controls, operation of the controls is becoming more complex and requires the driver's attention [2, 3]. According to Norman [4] new technologies are supposed to simplify life for drivers, but due to the rising complexity of these systems they actually create a higher driving effort. This phenomenon is called the paradox of technology [4]. In order to resolve this paradox and with regard to the development of new control devices, an unambiguous feedback in haptics, optics (e.g. backlight) and acoustics (e.g. click sounds) which improves the perception of controls is necessary [5].

Former research has largely focused on specifications of single modalities. Thus Hampel [6] and Reisinger [7] for example analyzed the haptic parametrization and derive concrete recommendations for designing haptic controls. In addition Kuehner [8] investigated the haptic differentiation of technical parameters such as inertia, damping and friction. However, there have also been some studies addressing the interaction between multiple modalities. The interaction between haptics and acoustics has been examined by Anguelov [9]. According to his research, an average or bad haptic perception of controls can be improved by a click sound with high perceived quality [9]. Kauer et al. [10] also stressed that a tactile feedback in combination with an auditory feedback results in higher detection rates than tactile feedback on its own. Treiber [11] implied that acoustic feedback from a rotatory control device increases the speed and accuracy of operating the device. Hoggan et al. [12] showed that when a touchscreen is used for mobile devices, both rectangular and curved buttons were perceived as congruent with different audio/tactile feedback. Wickens [13] also stressed that providing multimodal feedback in Human-Machine Interaction reduces workload during operation.

Nevertheless, in the context of controls in vehicles, there are no experimental studies covering all three modalities namely haptics, acoustics and optics. Two studies were therefore conducted to examine multimodal interaction.

The objective of the first study was to investigate the mutual interactions of haptic, acoustic and optic perception of control devices such as knobs used in vehicles. In this study the main effects and interactions between the operation sounds, haptics and controls' backlights were hence investigated.

Anguelov [9] furthermore indicated that the interaction of haptics and acoustics has an impact on the assessment of the perceived quality of control devices.

However, Anguelov's [9] research does not include detailed investigations on the relationship between the variation of acoustic and haptic parameters and their perception. Hence, a second study was conducted to examine the relationships between volume/sharpness/pitch and haptic perception.

2 Methods

To realize both studies, a questionnaire had to be developed and suitable technical parameters had to be identified.

2.1 Development of an Adequate Rating Scale

Prior to the study a literature research was conducted to design an adequate rating scale for testing the interaction between haptics, acoustics and optics.

When a questionnaire for this purpose is to be developed, the main psychometric criteria, objectivity, reliability and validity have to be considered [14, 15]. Recent studies showed that psychometric properties tend to increase with a rising number of response categories up to five or six response options [16–20]. Preston and Colman [19] found out that six or more response categories lead to a higher validity and higher discriminating power of the scales. Nevertheless, Weathers et al. [21] say that an increasing number of scale points also increases the difficulty in making decisions. Weijters et al. [22] recommend using rating scales based on the cognitive ability of the test persons. Hence, for the general population they suggest 5-point scales and for a student population 7-point scales [22]. O'Muircheartaigh et al. [23] stress that scales without a middle category have a lower reliability. If, on the other hand, scales with a middle category are used, there is the risk of the strong tendency towards the center because of an undifferentiated perception and assessment [24]. To reduce the possibility of a decrease in reliability Weng [17] and Krosnick and Berent [25] emphasize that labeling each scale leads to a higher reliability.

Based on this research a six-point scale, with labels for all six scale-points (*not at all, not, rather not, rather, very, extremely*) was used.

2.2 Rotatory Knob Simulator

To test the aforementioned interactions, a rotatory knob simulator was applied. This simulator was able to generate different sets of haptics (torque-angle characteristics), acoustics (click sounds) and optics (different backlight colors). Hampel [6], Kuehner [8] and Reisinger [7] used a test bench with sensors (torque and angle) and electric motors to simulate various torque-angle characteristics during their

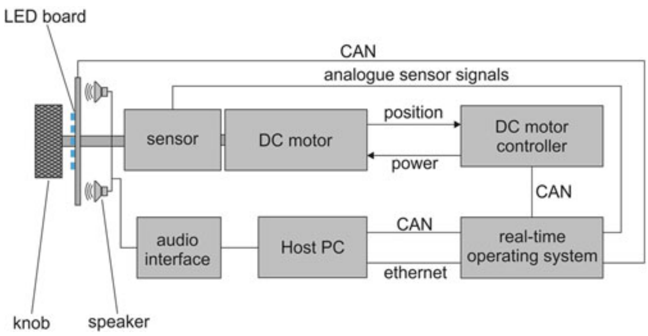


Fig. 1 Rotatory knob simulator—schematic construction

research. Nevertheless, none of the test benches provided an acoustic feedback. Hufenbach et al. [26] introduced a concept of a rotatory test bench with a variable software configuration of different torque-angle characteristics and acoustic feedback. Main components of this test bench are an electric motor, a position sensor and a suitable controller.

The rotatory knob simulator used in both experiments consists of a knob as an actuator, which is linked via a shaft to a sensor (torque-/angle-sensor and incremental rotatory encoder), a brushless DC motor and a DC motor controller. Both sensor and DC motor controller are connected up to a real-time operating system. Between the operating system and the Host PC the parameters of the torque-angle characteristics are transferred via Ethernet. Moreover, the operating system controls a LED board to set up different constant backlight colors. An additional CAN connection between Host PC and real-time operating system carries a signal every time an increment is reached and displays an acoustic signal via an audio interface and speakers. The schematic construction is shown in Fig. 1.

2.3 Identification of Haptic Parameters

Aiming at a pleasant haptic feedback, the knob had a constant diameter of 50 mm [9], an increment of 18°/20 detents and a constant sawtooth profile during both experiments [7].

During the first and the second study the rotatory knob simulator generated three different torques (25, 50, 75 mNm) which, according to Reisinger [7] (25 mNm), Anguelov [9] (30–40 mNm) and Hampel [6] (71–105 mNm), contribute to a comfortable perception. The backlight of the rotatory simulator could appear in three different colors (green, red, blue). Furthermore, the acoustics generated by the simulator varied between three click-sounds. Figure 2 illustrates the haptic characteristics during the first and second study with torque (M) and angle (φ).

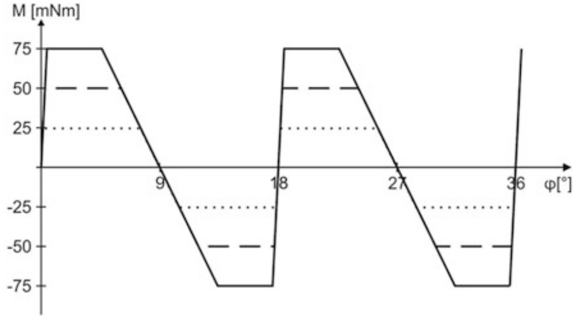


Fig. 2 Torque-angle characteristics (25 mNm, 50 mNm, 75 mNm/18°) referring to Reisinger's [7] pleasant angle-torque characteristics

2.4 Hypotheses and Experimental Design

In view of the absence of analyses of the interaction between the haptic, acoustic and visual modalities concerning control devices in vehicles, the following hypotheses were to be tested in the first study.

H1: The interaction between haptics and optics has an influence on the perception of acoustics.
H2: The interaction between haptic and acoustics has an influence on the perception of optics.
H3: The interaction between acoustics and optics has an influence on the perception of haptics.

In addition, the isolated influences (main effects) of all three modalities on each other are analyzed within the first study.

The experiment consisted of twelve different sets. Each set describes one particular configuration of the rotatory knob simulator with its visual, acoustic and haptic characteristics (e.g. 25 mNm, green backlight, click sound no. 1). Subjects were instructed to turn the knob for each set and subsequently answer a question on their perception. Concerning the haptics, in four of the twelve sets the torque remained constant (50 mNm) and the backlight colors (red vs. blue) and sounds (click-sound no. 1 vs. click sound no. 2) were varied in two levels. After each of these four sets subjects had to answer the question "*How distinctly do you perceive the haptics?*" on the six-point rating scale. Moreover, in four other sets the click sound was unchanged (click sound no. 2) and haptics (25 mNm vs. 75 mNm) and optics (blue vs. red) were modified. Concerning these four sets, subjects were asked the question "*How distinctly do you perceive the acoustics?*" During four other sets, the backlight stayed constant (green), while haptics (25 mNm vs. 75 mNm) and acoustics (click sound no.1 vs. click sound no. 2) were changed. These sets were followed by the question *"How distinctly do you perceive the optics?*" To sum up, all three groups set up included one constant parameter and each combination of the non-constant modalities. All twelve sets (see Table 1) were presented to each subject in a randomized manner.

Table 1 Experimental design, interaction between haptics, acoustics and optics (first study)

Set	Configuration rotatory simulator			Evaluation	
	Haptics [torque] (mNm)	Acoustics [click sound]	Optics [backlight]	Modality	Parameter
A	25	No. 3	Red	Acoustics	No. 3
B	25	No. 3	Blue	Acoustics	No. 3
C	75	No. 3	Red	Acoustics	No. 3
D	75	No. 3	Blue	Acoustics	No. 3
E	25	No. 1	Green	Optics	Green
F	25	No. 2	Green	Optics	Green
G	75	No. 1	Green	Optics	Green
H	75	No. 2	Green	Optics	Green
I	50	No. 1	Red	Haptics	50 mNm
J	50	No. 1	Blue	Haptics	50 mNm
K	50	No. 2	Red	Haptics	50 mNm
L	50	No. 2	Blue	Haptics	50 mNm

In order to investigate Anguelovs' [9] assumption concerning the relationship of haptics and acoustics in more detail, the effects of the variation of particular acoustic parameters on haptics and the effects of haptics on the acoustic parameters were analyzed in the second study. More precisely, the second study aimed at answering the following questions:

Q1: Is there a linear relationship between the sharpness of a click sound and the perception of the stiffness in haptics?
Q2: Is there a linear relationship between the pitch of a click sound and the perception of the stiffness in haptics?
Q3: Is there a linear relationship between the volume of a click sound and the perception of the stiffness in haptics?
Q4: Is there a linear relationship between the stiffness in haptics and the perception of sharpness?
Q5: Is there a linear relationship between the stiffness in haptics and the perception of pitch?
Q6: Is there a linear relationship between the stiffness in haptics and the perception of volume?

In total, three acoustic parameters and the torque of the rotatory knob simulator were varied in three steps each (see Table 2). The variation in the acoustic parameters was realized by manipulating click sound no. 3 from the first study.

In nine of the total 18 sets in total the click sound was manipulated in sharpness, pitch or volume, while the haptic parameter torque stayed constant at 50 mNm (sets a to i). Sharpness was varied between −5 dB/1500 Hz and +5 dB/600 Hz (unsharp) versus +5 dB/1500 Hz and −5 dB/600 Hz (sharp) compared to the regular click sound (sets a to c). Pitch (sets d to f) was manipulated in four halftones lower

Table 2 Experimental design, interaction between haptics and acoustics (second study)

Set	Configuration rotatory simulator				Evaluation	
	Haptics [torque] (mNm)	Acoustics			Modality	Parameter
		[sharpness]	[pitch]	[volume]		
a	50	Unsharp	Regular	Regular	Haptics	50 mNm
b	50	Regular	Regular	Regular	Haptics	50 mNm
c	50	Sharp	Regular	Regular	Haptics	50 mNm
d	50	Regular	Low-pitched	Regular	Haptics	50 mNm
e	50	Regular	Regular	Regular	Haptics	50 mNm
f	50	Regular	High-pitched	Regular	Haptics	50 mNm
g	50	Regular	Regular	Silent	Haptics	50 mNm
h	50	Regular	Regular	Regular	Haptics	50 mNm
i	50	Regular	Regular	Loud	Haptics	50 mNm
j	25	Regular	Regular	Regular	Acoustics	Volume
k	50	Regular	Regular	Regular	Acoustics	Volume
l	75	Regular	Regular	Regular	Acoustics	Volume
m	25	Regular	Regular	Regular	Acoustics	Sharpness
n	50	Regular	Regular	Regular	Acoustics	Sharpness
o	75	Regular	Regular	Regular	Acoustics	Sharpness
p	25	Regular	Regular	Regular	Acoustics	Pitch
q	50	Regular	Regular	Regular	Acoustics	Pitch
r	75	Regular	Regular	Regular	Acoustics	Pitch

(low-pitched) and four halftones higher (high-pitched). The variation of the volume (sets g to i) differed from the regular click sound in −5 dB (silent) and +5 dB (loud). After each of these nine sets, subjects had to answer the question "*How stiff do you perceive the haptics?*". Within the other nine sets (j to r) the click sound remained unaltered, while the torque was varied. The characteristics of the haptics were the same as during the first study (25, 50 and 75 mNm). The question after sets j to l was "*How loud do you perceive the acoustics?*". After sets m to o subjects were asked "*How sharp do you perceive the acoustics?*" and after sets p to r subjects had to answer the question "*How high do you perceive the acoustics?*". All in all six of 18 sets had the same configuration (b, e, h, k, n, q). Again, all sets were presented to subjects in a randomized manner.

2.5 Statistical Analysis

As can be seen in Table 1, the first study can be subdivided into three 2 × 2-factorial designs. In each of these designs, the evaluated modality is held constant while the other two modalities are varied in two steps. Consequently, each time a two-way repeated measures ANOVA was used for statistical analysis. Table 2 gives an overview of the experimental design of the second study. For each of the six questions under examination represented by a triplet of sets one-way repeated-measures ANOVA was conducted. If there were any significant main effects, linear contrasts were calculated in order to test for linear effects of the independent variable on the dependent variable. For all analyses the level of significance was set at $\alpha = 0.05$.

3 Results

3.1 *Study 1: Examination of Interactions of Haptics, Optics and Acoustics*

The first study was conducted with N = 32 subjects (M = 32.81 years, SD = 8.75, 11 females and 21 males). More than two-thirds stated that they drive more than 10,000 km (≙ 6213 miles) a year. None of the subjects suffered from sensory impairments (e.g. sudden deafness or strong amblyopia). Concerning H1, the data from one subject were lost due to technical failure.

To sum up, no significant results could be observed. The statistical analysis for H1 (see Table 3) shows that the interaction of haptics and optics did not influence the perception of acoustics ($F(1, 30) = 1.30$, $p = 0.264$). Besides, the main effect of haptics ($F(1, 30) = 0.00$, $p = 1.00$) and optics ($F(1, 30) = 3.21$, $p = 0.083$) did not reach significance. Thus, neither haptics nor optics by themselves influenced the perception of acoustics.

For H2 (see Table 4) the results are very similar: The interaction of acoustics and haptics did not significantly influence the perception of optics ($F(1, 31) = 0.33$, $p = 0.572$). The analysis also revealed no main effects of acoustics ($F(1, 31) = 3.83$, $p = 0.059$) or haptics ($F(1, 31) = 0.04$, $p = 0.839$) on the perception of optics. Thus, neither haptics nor acoustics by themselves influenced the perception of optics.

Finally, the analysis for H3 (see Table 5) showed a non-significant influence of the interaction of optics and acoustics ($F(1, 31) = 0.21$, $p = 0.647$) as well as non-significant main effects of acoustics ($F(1, 31) = 2.38$, $p = 0.133$) and optics (F

Table 3 Evaluation of acoustics (H1)

Optics [backlight]	Haptics [torque]		
	25 mNm	75 mNm	
red	$M = 4.45$, $SD = 0.72$	$M = 4.55$, $SD = 0.62$	$M = 4.50$, $SD = 0.67$
blue	$M = 4.74$, $SD = 0.51$	$M = 4.65$, $SD = 0.80$	$M = 4.69$, $SD = 0.67$
	$M = 4.60$, $SD = 0.64$	$M = 4.60$, $SD = 0.71$	

Table 4 Evaluation of optics (H2)

Haptics [torque] (mNm)	Acoustics [click sound]		
	No. 1	No. 2	
25	*M* = 3.87, *SD* = 0.79	*M* = 3.69, *SD* = 0.97	*M* = 3.78, *SD* = 0.88
75	*M* = 3.84, *SD* = 0.72	*M* = 3.75, *SD* = 0.67	*M* = 3.80, *SD* = 0.69
	M = 3.86, *SD* = 0.76	*M* = 3.72, *SD* = 0.83	

Table 5 Evaluation of haptics (H3)

Acoustics [click sound]	Optics [backlight]		
	red	blue	
no. 1	*M* = 4.91, *SD* = 0.69	*M* = 4.72, *SD* = 0.63	*M* = 4.81, *SD* = 0.66
no. 2	*M* = 4.69, *SD* = 0.82	*M* = 4.59, *SD* = 0.62	*M* = 4.64, *SD* = 0.72
	M = 4.80, *SD* = 0.76	*M* = 4.66, *SD* = 0.62	

(1, 31) = 2.04, p = 0.163) on the perception of haptics. Thus, neither acoustics nor optics by themselves influenced haptic perception.

The results of the first study corroborate the assumption that no systematic relationships between the perception of haptics, optics and acoustics exist.

3.2 Study 2: Examination of the Relations Between Haptics and Acoustic Parameters

To investigate the interaction between variations of certain acoustic parameters and haptics in detail, N = 34 subjects were tested (M = 31.18 years, SD = 8.56, 21–58 years old, 11 females and 23 males).

The results for Q1 to Q3 (see Table 6) suggest that there is no difference in the perception of haptics between different levels of the sharpness, pitch or volume of the presented click-sound, since neither the main effect of sharpness (F(1, 71, 56.27) = 0.29, p = 0.714) nor of pitch (F(2, 66) = 0.98, p = 0.381) nor of volume (F(2, 66) = 0.75, p = 0.477) reached significance. The identical means and standard deviations for questions Q1 to Q3 can be explained by the fact that the respective sets b, e and h, had an identical configuration. This configuration was therefore presented to the subjects only once during the experiment, but the result is included in the analysis for all three questions. Concerning the influence of acoustic parameters on the perception of haptics, no significant effects of volume (F(2, 66) = 2.85, p = 0.065) and sharpness (F(2, 66) = 1.17, p = 0.316) could be detected either (Q4 and Q5).

Table 6 Evaluation of the second study

	Acoustics			
	Unsharp	Regular	Sharp	**Evaluation**
Q1	M = 3.97, SD = 0.87	M = 3.88, SD = 1.04	M = 3.82, SD = 1.06	Haptics
	Low-pitched	Regular	High-pitched	
Q2	M = 3.68, SD = 1.01	M = 3.88, SD = 1.04	M = 3.88, SD = 0.95	Haptics
	Silent	Regular	Loud	
Q3	M = 4.06, SD = 0.93	M = 3.88, SD = 1.04	M = 4.09, SD = 1.03	Haptics
	Haptics			
	25 mNm	50 mNm	75 mNm	
Q4	M = 4.00, SD = 0.89	M = 3.71, SD = 1.17	M = 3.71, SD = 0.94	Acoustics (volume)
	25 mNm	50 mNm	75 mNm	
Q5	M = 3.74, SD = 1.34	M = 3.76, SD = 1.21	M = 3.47, SD = 1.16	Acoustics (sharpness)
	25 mNm	50 mNm	75 mNm	
Q6	M = 3.18, SD = 1.01	M = 2.71, SD = 1.00	M = 2.62, SD = 1.01	Acoustics (pitch)

However, results for Q6 yield a significant effect of the pitch on the perception of haptics ($F(2, 66) = 3.67$, $p = 0.031$, $\eta 2 = 0.100$). Furthermore, contrasts revealed a significant linear trend in the data ($F(1, 33) = 5.124$, $p = 0.030$, $\eta 2 = 0.134$): With an increasing torque subjects perceived the click sound as increasingly low-pitched (see Fig. 3). Therefore, our results suggest a linear relationship between the torque of a rotatory control element and its acoustic perception: The higher the torque of the rotatory control element, the lower the perception of the acoustics' pitch.

In contrast, the results show that alternation of acoustic characteristics has no effect on the haptic assessment of controls. Neither sharpness, pitch nor volume has

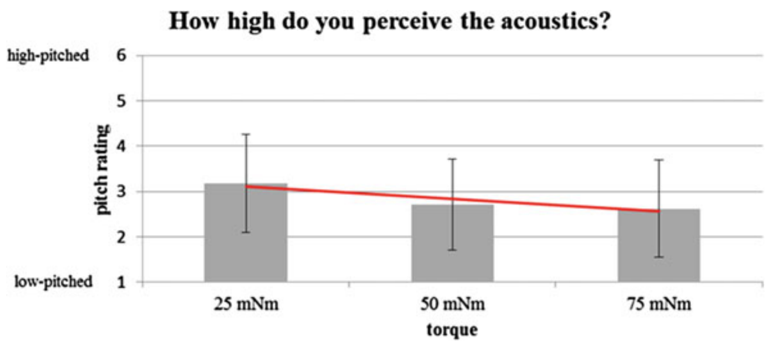


Fig. 3 Perception of the pitch subject to haptics (torque)

an influence on the haptic perception. General statements like "the unsharper/louder/lower-pitched the acoustics of controls, the stiffer is their haptic perception" cannot be justified.

4 Discussion

The two studies further also investigated the interactions of optics, acoustics and haptics in the assessment and description of controls (e.g. knobs). While in the first study none of the three modalities influenced the others, the more detailed analysis during the second study revealed dependencies between the acoustics and the assessment and description of the haptics. The detailed results clearly show that the dependence is unidirectional. As the results indicate, haptics has an influence on the perception of the pitch, while sharpness and volume remain independent. The lack of influence of acoustics on haptics confirms recent studies, which found that, with regard to the holistic description and assessment of controls, haptics is more influential than the acoustics. Nevertheless, the influence, which does exist, shows that haptics and acoustics have to be well-matched within the vehicle development process (see Fig. 4).

The influence of optics, on the other hand, can be disregarded, given the results of the study and the following two considerations: (1) Backlight is not always present during driving of a vehicle due to varying insolation during daytime and (2) in assessment of the backlight of controls, operating the control is not necessary, which prevents the interaction of optics with acoustics and haptics.

Taken together, haptics and acoustics can be seen as more influential and should thus be harmonized when future control devices are designed.

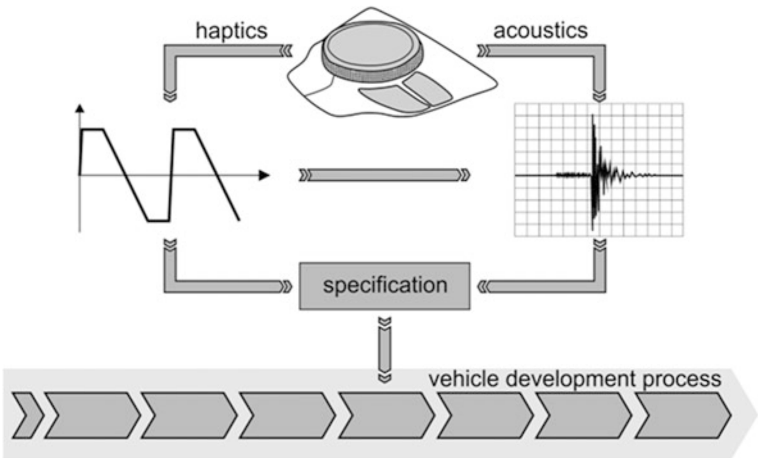


Fig. 4 Design and development of controls

References

1. Kim, K., Kim, J., Choi, J., Kim, J., Lee, S.: Depth camera-based 3D hand gesture controls with immersive tactile feedback for natural mid-air gesture interactions. Sensors **15**(2015), 1022–1046 (2015)
2. Akyol, S., Libuda, L., Krais, K.-F.: Multimodale Benutzung adaptiver Kfz-Bordsysteme. In: Juergensohn, T., Timpe, K.-P. (eds.) Kraftfahrzeugfuehrung, pp. 137–154. Springer, Berlin (2001)
3. Schattenberg, K., K., Debus, G.: Multimodale Anzeige- und Bedienkonzepte zur Steuerung technischer Systeme waehrend der Fahrt im Kraftfahrzeug: Evaluationsbefunde zur Systemweiterentwicklung mit paralleler Sprachbedienung. In: Juergensohn T., Timpe K.-P. (eds.) Kraftfahrzeugfuehrung, pp. 177–193. Springer, Berlin (2001)
4. Norman, D.A.: The Design of Everyday Things: Revised and Expanded Edition, pp. 32—34. Basic Books, New York (2013)
5. Glohr, T., Wahn, N., Fritz, M., Maier, T.: Haptics as an aspect of the perceived quality of control devices in trucks. In: 6th International Conference on Applied Human Factors (AHFE 2015) and the Affiliated Conferences, pp. 3226–3233, Las Vegas 2015
6. Hampel, T.: Untersuchungen und Gestaltungshinweise für adaptive multifunktionale Stellteile mit aktiver haptischer Rückmeldung. Dissertation, Universität Stuttgart (2011)
7. Reisinger, J.: Parametrisierung der Haptik von handbetätigten Stellteilen. Dissertation, TU München (2009)
8. Kuehner, M.: Haptische Unterscheidbarkeit mechanischer Parameter bei rotatorischen Bedienelementen. Dissertation, TU München (2014)
9. Anguelov, N.: Haptische und akustische Kenngrößen zur Objektivierung und Optimierung der Wertanmutung von Schaltern und Bedienfeldern für den Kfz-Innenraum, Dissertation, TU Dresden (2009)
10. Kauer, M., Schreiber, M., Hakuli, S., Bruder, R.: Taktil oder akustisch? Der Einfluss der Akustik auf die Wahrnehmung der taktilen Rückmeldung bei taktilen Touchscreen. In: Lichtenstein, A., Stoeßel, C., Clemens, C. (eds.) Der Mensch im Mittelpunkt technischer Systeme, 8. Berliner Werkstatt Mensch-Maschine-Systeme, VDI, Duesseldorf (2009)
11. Treiber, A.: Design and benchmarking of acoustic feedback in human machine interface. Dissertation, Slovak University of Technology, Bratislava (2011)
12. Hoggan, E., Kaaresoja, T., Laitinen, P., Brewster, S.: Crossmodal congruence: the look, feel and sound of touchscreen widgets. In: ICMI'08 Proceedings of the 10th International conference on Multimodal interfaces, pp. 157–164, ACM, New York (2008)
13. Wickens, C.D.: Multiple resources and performance prediction. Theor. Issues Ergon. Sci. **3**, 159–177 (2002)
14. Moosbrugger, H., Kelava, A.: Einfürhung und zusammenfassender Überblick. In: Moosbrugger, H., Kelava, A. (eds.), Testtheorie und Fragebogenkonstruktion; Springer, Berlin, Heidelberg, 2. Auflage, pp. 1–4 (2012)
15. Lienert, G.A.: Raatz: Testaufbau und Testanalyse, 6th edn. Beltz, Weinheim (1998)
16. Aiken, Lewis R.: Number of response categories and statistics on teacher rating scale. Educ. Psychol. Measur. **43**, 397–401 (1983)
17. Weng, L.-J.: Impact of the number of response categories and anchor labels on coefficient alpha and test-retest reliability. Educ. Psychol. Measur. **64**(6), 956–972 (2004)
18. McCallum, L.S., Keith, B.R., Wiebe, D.T.: Comparison of response formats for multidimensional health locus of control scales: six levels versus two levels. J. Pers. Assess. **52**, 732–736 (1988)
19. Preston, C., Colman, A.: Optimal number of response categories in rating scales: reliability, validity, discriminating power, and respondent preferences. Acta Psychol. **104**, 1–15 (2000)
20. Lozano, L.M., Garcia-Cueto, E., Muniz, J.: Effect of the number of response categories on the reliability and validity of rating scales. Methodology **4**(2), 73–79 (2008)

21. Weathers, D., Sharma, S., Niedrich, R.W.: The impact of the number of scale points, dispositional factors, and the status quo decision heuristic on scale reliability and response accuracy. J. Bus. Res. **58**, 1516–1524 (2005)
22. Weijters, B., Cabooter, E., Schillewaert, N.: The effect of rating scale format on response styles: the number of response categories and response category labels. Int. J. Res. Market. **27**, 236–247 (2010)
23. O'Muircheartaigh, C., Kosnick, J., Helic, A.: Middle Alternatives, Acquiescene, and the Quality of Questionnaire Data. University of Chicago (2000)
24. Greving, B.: Messen und Skalieren von Sachverhalten. In: Albers, S., Klapper, D., Konradt, U., Walter, A., Wolf, J. (eds.) Methodik der empirischen Forschung, 3rd edn, pp. 65–78. Gabler Verlag, Wiesbaden (2009)
25. Krosnick, J.A., Berent, M.K.: Comparisons of party identification and policy preferences: the impact of survey question format. Am. J. Polit. Sci. pp. 941–964 (1993)
26. Hufenbach, W., Prengel, S., Dannemann, M.: Prüfstandsentwicklung zur Identifizierung des haptischen und akustischen Einflusses auf die Wertigkeit von Bedienelementen. In: Möser, M. (eds.) Fortschritte der Akustik, DAGA Berlin, pp. 863–864 (2010)

Conducting a Prospective Review for Enhanced Interface Features for Unmanned Ground Vehicle Operation

Teena M. Garrison, Leif T. Jensen, Lucas Cagle, John A. McGinley, Daniel W. Carruth, Cindy L. Bethel, Christopher T. Goodin and Phillip J. Durst

Abstract When developing new interface features, it is vital to consider the perspectives of users from several backgrounds throughout the process, in order to ensure features that address realistic user concerns in effective ways. The Systematic Human Error Reduction and Prediction Approach (SHERPA) and an established user acceptance questionnaire were used to evaluate the predicted usability and acceptability of four enhanced interface features for unmanned ground vehicle (UGV) operation. The targeted interface is designed for use in real-world and simulated environments. Although the SHERPA results alone did not clearly distinguish between interface enhancements, the user acceptance results from team members converged on a single 'best' interface enhancement for supporting

T.M. Garrison (✉) · L.T. Jensen · L. Cagle · J.A. McGinley · D.W. Carruth · C.L. Bethel
Center for Advanced Vehicular Systems, Mississippi State University, Mississippi State, MS, USA
e-mail: teenag@cavs.msstate.edu

L.T. Jensen
e-mail: leif@cavs.msstate.edu

L. Cagle
e-mail: lucas@cavs.msstate.edu

J.A. McGinley
e-mail: jam@cavs.msstate.edu

D.W. Carruth
e-mail: dwc2@cavs.msstate.edu

C.L. Bethel
e-mail: cbethel@cse.msstate.edu

C.L. Bethel
Computer Science and Engineering, Mississippi State University, Mississippi State, MS, USA

C.T. Goodin · P.J. Durst
U.S. Army Engineer Research and Development Center, Vicksburg, MS, USA
e-mail: Christopher.T.Goodin@erdc.dren.mil

P.J. Durst
e-mail: Phillip.J.Durst@erdc.dren.mil

M. Soares et al. (eds.), *Advances in Ergonomics Modeling, Usability & Special Populations*, Advances in Intelligent Systems and Computing 486,
DOI 10.1007/978-3-319-41685-4_54

collision avoidance and navigation, based on assessments using early mock-ups in a simulated environment.

Keywords Human-robot interaction · Human error · User acceptance

1 Introduction

The use of unmanned ground vehicles (UGV) for military and tactical operations has been established for some time [1–3], but improved networking and communication capabilities have allowed greater operating distances. Increases in available bandwidth underlie improved video resolution, often removing the necessity to maintain line-of-sight for effective operation and supporting new and broader applications. Unfortunately, these improvements in technical capabilities have also generated new challenges in UGV operation, particularly regarding vehicle navigation and collision avoidance in remote environments. The standard drive camera perspective of a Jaguar V4 [4], track-driven UGV (Fig. 1) does not allow the operator to see the location of the outboard flippers. Without this information, these flippers may catch on environment features such as wall corners, furniture, and debris.

Improvements to a recently developed user interface for operation of a UGV were evaluated by members of the research team using established methods for evaluating human error and user acceptance. The four interface enhancements were all designed to improve operator awareness of the potential for collisions with environment features, in comparison to the video-only information generally available. The UGV platform of interest was the Jaguar V4.

Fig. 1 Drive camera views from a Jaguar V4 UGV (*left*), and from the simulated Jaguar V4 platform in the Automated Navigation Virtual Environment Laboratory (ANVEL) simulation environment (*right*)

2 Methods

2.1 Enhanced Interface Features

Four distinct enhancements were developed based on previous human-robot interaction literature by [5]. Distance Indicator bars (A) were added to the upper left and right corners to provide color-coded cues to relative distance from objects in the environment. Virtual flippers (B) were added to the lower portion of the video feed to remind operators of the flippers' presence on the UGV platform. Distance guidelines (C), similar to those used in some rear-view cameras in the automotive industry, were added as an overlay to the standard video feed. A virtual path (D) was overlaid over the video, including an optimal path and an alignment indicator. Figure 2 provides representative mock-ups of each of the interface enhancements.

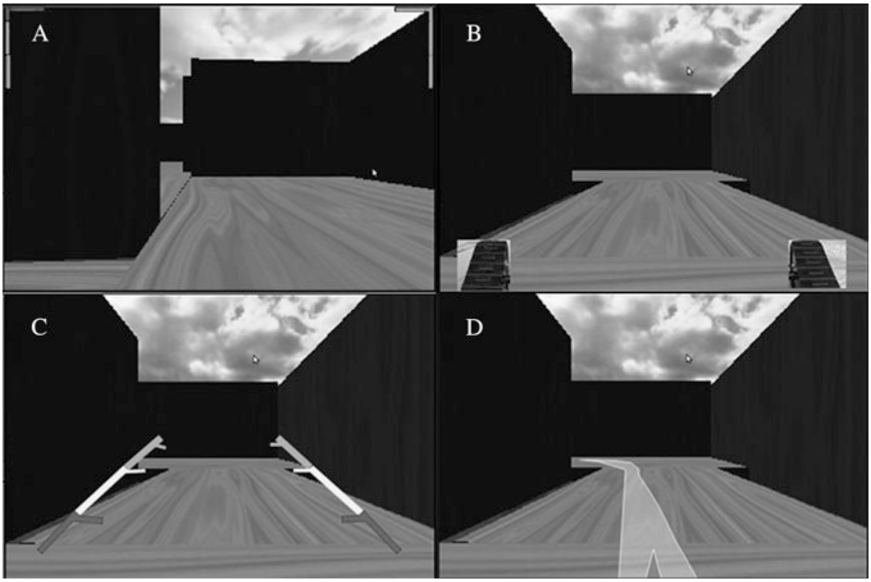


Fig. 2 The four interface enhancements evaluated in the prospective review: distance indicator bars (**a** *upper left*), virtual flippers (**b** *upper right*), distance guidelines (**c** *lower left*), and virtual path (**d** *lower right*). For distance indicator bars and distance guidelines

2.2 Review Procedure

The prospective review was performed as part of a project to improve remote human-robot interaction in tactical and military operations. This includes the development of a customized PC-based interface that can be used with both the actual Jaguar V4 UGV platform and a simulated model available in the Automated Navigation Virtual Environment Laboratory (ANVEL) simulation environment. Four research team members evaluated the interfaces using the Systematic Human Error Reduction and Prediction Approach (SHERPA; [6, 7]). The participating research team members' backgrounds and education levels varied substantially: two software developers (an undergraduate student and a professional software engineer experienced in human factors research) and two human factors specialists (a graduate student and a research faculty member). An additional undergraduate student only completed the user acceptance questionnaire.

Each research team member was provided with a set of mock-ups for the proposed enhanced interface features to facilitate their prospective reviews, and each followed the SHERPA guidelines to evaluate the potential for user error. Finally, each reviewer also provided predictions for user acceptability and acceptance for each enhanced feature, based on established user acceptance questionnaires [8, 9].

3 Results

Table 1 includes the total number of errors reported by each reviewer for each of the proposed enhancements. Across all four proposed enhancements, the undergraduate software developer and the professional software engineer consistently identified more potential errors than the two human factors specialists. Many of these errors were of a more technical nature rather than related to human error per se, but they were included for completeness and because they could impact anticipated interaction (and were therefore relevant to the overarching goal). In addition, the human factors graduate student reported more potential errors than the faculty member. These results are in line with the results in [6] that showed an overall decrease in the number of errors reported with practice among novices, with regard to background differences in backgrounds for the reviewers. The results

Table 1 Total number of prospective errors reported by each reviewer and overall for each proposed interface enhancement

Interface enhancement	HF-F	HF-G	SD-UG	SD-P	Overall
Distance indicator bars	37	65	133	109	344
Virtual flippers	31	59	129	113	332
Distance guidelines	31	58	133	103	325
Virtual path	32	59	119	118	328

Table 2 Representative examples of prospective errors reported for each proposed interface enhancement

Interface enhancement	Example	Reviewer(s)
Distance indicator bars	[Operator] Did not check (or review fully) current location, status	HF-F, HF-G, SD-UG, SD-P
Virtual flippers	[Operator] Did not make correct/accurate/necessary adjustments	SD-UG, SD-P
Distance guidelines	[Operator] Did not move flipper to needed/desired position	SD-UG, SD-P
Virtual path	[Operator] Failed to complete [indicator] check	HF-G, SD-P

indicated roughly the same number of errors for the four interface enhancements, and indeed many of these were consistent across the proposed enhancements, although the indicator bars (Fig. 1, upper left) were considered most problematic. Table 2 provides brief, representative examples of potential errors reported by participating team members for each enhancement.

Although the SHERPA results did not clearly identify a preferred interface approach, the user acceptance results did converge to a single preference. The virtual path (Fig. 2, lower right) was universally preferred by the research team members (including the additional undergraduate student who provided acceptance ratings; Fig. 3, bottom). The other three enhanced features were more varied in their

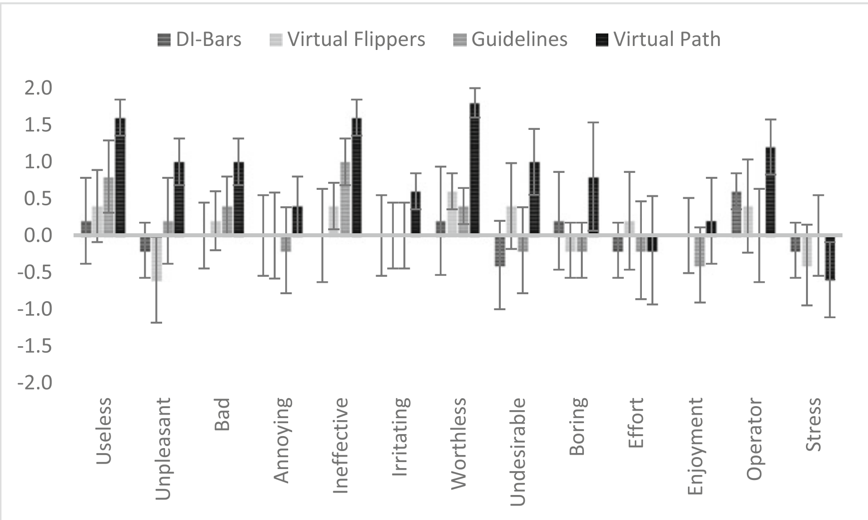


Fig. 3 The overall user acceptance scores in the prospective review: distance indicator bars, virtual flippers, distance guidelines, and virtual path. The label indicates the first of the two semantic differential scale anchors provided (e.g., Useless-Useful, Unpleasant-Pleasant, etc.). Two items, ‘effort’ (lower-higher) and ‘stress’ (lower-higher), were reverse-scored

acceptability reviews, with the distance indicator bars being rated slightly lower overall (see remaining panels in Fig. 3). Note that these charts include additional ratings by an undergraduate software developer; removing this set of ratings does not impact the overall pattern of user acceptance results—if anything the preference for the virtual path becomes more apparent.

4 Conclusions

4.1 Implications

The prospective review by collaborating team members highlighted a number of benefits and weaknesses regarding the usability of the proposed interface features. Although none of the interface enhancements evaluated really stood out from the others in overall comparisons, the distance indicator bars seem to have the greatest potential for human error in anticipated use. One factor in this review may be their relative location at the upper extremes of the simulated camera view, in comparison with those of the other interface enhancements in more central locations. Another potential factor in the number of errors is the use of color (indeed, one reviewer is color-blind and commented explicitly on challenges in making judgments); however, this concern also applies to other proposed interface enhancements (i.e., distance guidelines). The reviewer's comments highlighted a more general concern that should be addressed prior to implementation in either a simulated or real-world environment.

With regard to the user acceptance results, the generally preferred enhancement (virtual path) is also the most technically challenging to implement in practice, as it requires a dynamic map and the calculation of distances from objects in real-time. The other proposed features have fewer requirements for real-time processing of the environment, but were also viewed as less informative and useful. There appears to be a practical trade-off between feature flexibility and perceived effectiveness in the task.

More generally, the use of SHERPA seemed to bring the varied backgrounds of the reviewers to a 'common ground'; although the software developers identified more potential errors than the human factors specialists overall, there was substantial agreement across reviewers about how the enhanced system interface would operate—although the structure of SHERPA itself lends itself to this systematic approach, it is useful to note that the interpretations that the reviewers made did appear to be consistent with the use of shared materials, without additional discussion and detail. Indeed, as a research group (both those who completed the review and those who did not), we attempted to limit discussion of these particular interface features to minimize potential bias in the review process. Thus, the consistency in interpretations is more likely to be a benefit attributable to the SHERPA review, rather than to a pre-review shared model of the interface enhancements.

SHERPA's validity as a human error assessment is already well-established in the literature [6, 7, 10]. Nevertheless, the current results further support this finding with limited training required prior to its use.

4.2 Limitations

Although the participating team members captured a wide range of experience and domain expertise, they were a small sample within a larger research team. A practical challenge of using a systematic review process is the inherent time requirements. Indeed, the full research team was requested to complete the described review, but less than half actually completed the full assessment. One can anticipate that this limitation is not limited to participation in our own research team, but would generalize to any large research group with competing deadlines and task assignments. Ergonomics practitioners working in industry and military settings are likely quite familiar with this particular aspect of interface design and development. However, even with the relatively low response rate among our group, we still gathered a promising amount of information that can guide our continued development of the UGV operator interface, and the time requirements, although daunting in some ways, are still likely to be less than if development and revision tasks were based purely on retrospective performance reviews of the interface functionality [11].

Additionally, all of the team members are familiar with how the Jaguar V4 UGV operates in both real-world and simulated environments, and this familiarity almost certainly guided their reviews. A novice operator sample might find the resulting interface to be of only limited effectiveness. However, because this review process preceded the actual implementation of the proposed interface enhancements, some basic background is required to constrain expectations and predictions. A second review with a sample of end-user operators would still be required to truly evaluate feature effectiveness and usability following implementation.

Acknowledgments Material presented in this paper is a product of the CREATE-GV Element of the Computational Research and Engineering Acquisition Tools and Environments (CREATE) Program sponsored by the U.S. Department of Defense HPC Modernization Program Office. This effort was sponsored under contract number W912HZ-13-C-0037.

References

1. Schipani, S.P.: An evaluation of operator workload, during partially-autonomous vehicle operations. In: 2003 Performance Metrics for Intelligent Systems (PerMIS '03) Workshop (2003)
2. Bethel, C.L., Carruth, D., Garrison, T.: Discoveries from integrating robots into SWAT team training exercises. In: 10th IEEE International Symposium on Safety, Security, and Rescue Robotics (2012)

3. Dehais, F., Causse, M., Tremblay, S.: Mitigation of conflicts with automation: use of cognitive countermeasures. Hum. Factors **53**, 448–460 (2011)
4. Jaguar V4 Platform Specification. Dr. Robot, Inc. http://jaguar.drrobot.com/specification_v4.asp
5. Keyes, B., Micire, M., Drury, J.L., Yanco, H.A.: Improving human-robot interaction through interface evolution. In: Chugo, D. (ed.) Human-Robot Interaction. Intech, Croatia (2010)
6. Stanton, N.A., Stevenage, S.V.: Learning to predict human error: issues of acceptability, reliability and validity. Ergonomics **41**, 1737–1756 (1998)
7. Harris, D., Stanton, N.A., Marshall, A., Young, M.S., Demagalski, J., Salmon, P.: Using SHERPA to predict design-induced error on the flight deck. Aerosp. Sci. Technol. **9**, 525–532 (2005)
8. Van Der Laan, J.D., Heino, A., De Waard, D.: A simple procedure for the assessment of acceptance of advanced transport telematics. Transp. Res. C. **5**, 1–10 (1997)
9. Adell, E., Várhelyi, A.: Driver comprehension and acceptance of the active accelerator pedal after long-term use. Transp. Res. F. **11**, 37–51 (2008)
10. Bligard, L.-O., Osvalder, A.-L.: Predictive use error analysis—development of AEA, SHERPA and PHEA to better predict, identify and present use errors. Int. J. Ind. Ergon. **44**, 153–170 (2014)
11. Baber, C., Stanton, N.A.: Human error identification techniques applied to public technology: predictions compared with observed use. Appl. Ergon. **27**, 119–131 (1996)

Physiological Responses Related to Visual Impressions of a Product: Evaluating Automobile Interior Design

Hidemaru Muto, Tsuneyuki Yamamoto, Naoki Kamiya and Miwa Nakanishi

Abstract In many products, the visual impressions of the product are extremely important components—sight accounts for 83 % of the five senses (An education apparatus editing committee in An industrial education apparatus system manual. JUS Press 1972). However, manufacturers still depend on the aspect of the effectiveness, efficiency, and usability for the design evaluation of products; yet, consumer emotion is hard to measure because the mental side of users such as visual impressions cannot be observed directly and the index to measure them has not been established. The function, performance, and usability can be measured by the behavioral index of users (e.g., operation time and error rate) (Nagashima and Kubo in The sensitivity and information for the new manufacturing. Morikita Shuppan Co., Ltd, 2007). In this study, we experimentally searched for indices to objectively detect the impression of appearance with car images as targets. We observed that MPFC activation is related to high "familiarity" and low "mechanical" features.

Keywords Physiological responses · Subjectivity evaluation · Car appearance

1 Introduction

Once an established product reaches maturity in terms of function, performance, and usability, marketing strategies need to appeal to consumers' thoughts and emotions via visual impressions to revive the product in consumers' minds. The design evaluation of cars includes not only functional aspects such as safety and

H. Muto (✉) · M. Nakanishi
Graduate School of Science and Technology, Keio University, Yokohama, Japan
e-mail: hidelcric@gmail.com

T. Yamamoto · N. Kamiya
Tokai Rika Co., Ltd., Aichi, Japan

M. Soares et al. (eds.), *Advances in Ergonomics Modeling, Usability & Special Populations*, Advances in Intelligent Systems and Computing 486,
DOI 10.1007/978-3-319-41685-4_55

performance characteristics but also a psychological aspect of the user including the comfort in the car and the joy of owning it. Thus, appearance plays a major role. During the design process, manufacturers suggest various concepts ("ecological," "luxurious," etc.) according to the needs of target users.

During this evaluation, determining whether users appreciate concepts intended by designers from the appearance of the embodied product is important. However, the evaluation of a delicate psychological factor such as "impression" depends on subjective methods [3]. There is no objective method to detect and quantify it.

In our research project, we have continued examination to possibly evaluate visual impressions objectively using physiological responses known to have combinations with affection and more. Muraji studied physiological responses and subjectively evaluated them [4]. He found combinations indicating the significance of correlation in several physiological responses and impression. However, the result is not sufficiently accurate; therefore, it is vitally important enhancing the versatility of the result to test it by another product.

In this study, we investigated various psychological effects and their connection with physiological responses when humans observe objects using an actual car image as the target.

2 Experiment Outline

2.1 Policy

We investigated the physiological responses of visual impressions of a product through examinations that measured subjectivity evaluation and physiological responses of car interior images as a stimulus. We used different domestic and international brands with to create differences in visual impressions. The study summary is as follows:

I. The choice of the characteristics to evaluate the visual impressions of cars
II. The choice of the car models to use as interior images
III. Various interior images were presented to participants. Physiological responses were measured at that time (Experiment 1)
IV. Present images used in III to participants again and measure subjectively evaluation using items selected in I (Experiment 2)
V. Analyze correlation of physiological responses and subjectively evaluation form Experiments 1 and 2
VI. Clarify the relation between visual impressions and physiological responses.

Table 1 25 items to evaluate visual impressions

Advanced	Graceful	Luxury	Powerful	Genuine
Useful	Comfortable	Colorful	Natural	Pleasant
Familiar	Eco	Light	Individual	Simple
Spacious	Fashionable	Delicate	Flexible	Sporty
Safe	Peaceful	Compact	Mechanical	Just like myself

2.2 The Characteristics to Evaluate Visual Impressions About Cars

Car manufacturers present their products as versatile to appeal to a wide array of buyers. We focused on the evaluation items that manufacturers use for advertising and tried to select those that users generally feel for cars.

In particular, we extracted 122 image words from web pages of 128 car models and then abstracted them into 25 image words using the KJ method. Consequently, we abstracted 25 items (Table 1). These can be thought to reflect the user's visual impressions about cars.

2.3 The Stimulus to Give Visual Impressions

In the preceding study, Muraji used 3DCG images of cars. A part of them is shown in Fig. 1.

In this study, we selected 30 actual car images from 26 makers and 64 car models manufactured locally and internationally with obvious differences. In each pattern, we prepared images from 3 viewpoints: driver, assistant driver, and back. Next, we made some slideshows the images. We removed the noise out of each image so that participants could get in the stimulus easily. Images of the car interiors taken from the rear are shown in Fig. 2. In addition, these original photos are provided by A2Mac1.

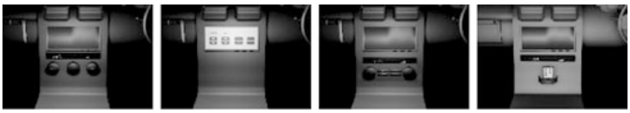


Fig. 1 3DCG images used in the preceding study

Fig. 2 30 images of the interior of cars from the back

2.4 *Measuring*

We conducted Experiment 1: Measuring physiological responses when participants observe the images of the interior of cars selected as stimulus. We measured the cerebral blood volume, skin conductance response, instant heart rate, and photo-plethysmogram levels.

[Record item]
The cerebral blood volume

The prefrontal cortex in the prefrontal area can be divided into 4 fields and is said to have different functions, respectively. [5, 6]

- Medial prefrontal cortex: MPFC
- Dorsolateral prefrontal cortex: DLPFC
- Ventrolateral prefrontal cortex: VLPFC
- Orbit frontal cortex: OFC.

In this study, we used OEG-16 (product made in Spectratech Corporation) that can measure the cerebral blood volume at 16ch by Near Infra-red Spectroscopy (NIRS) (Figs. 3 and 4).

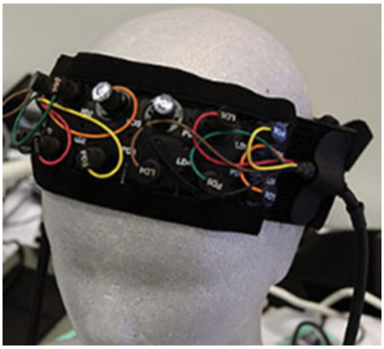


Fig. 3 OEG-16

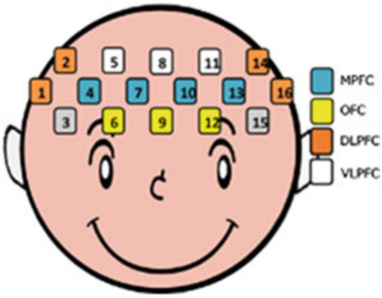


Fig. 4 The division of the brain domain in all ch16

Skin conductance response

The skin conductance response can be electrically measured from the sweat gland activities of mental sweat parts. According to past physiology studies, the skin conductance response is said to be an index indicating a degree of psychological excitement. In this study, we used MP150 (product made in BIOPAC Corporation) to measure the skin conductance response (Fig. 5).

Instant heart rate and photoplethysmogram levels

The heart rate and blood pressure reflect the activity of the autonomic nerve and are related to emotion and feelings [7, 8]. In this study, we used MP150 as mentioned above.

Fig. 5 MP150

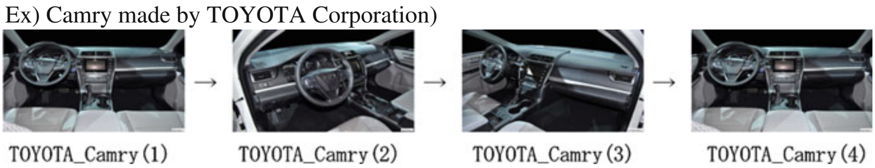


Fig. 6 The change of images

[Experiment environment, Experiment protocol]

Sitting participants attached OEG-16 on their heads and MP150 to the forefingers and middle fingers of the non-dominant hand. After that, they observed slideshows projected by 50 inches displays (product made in NEC Corporation) put in front of them. As represented in Fig. 6, we showed images from different angles every 10 s for all selected 30 car models so that the participant could get comprehensive visual impressions.

The image (1) = the image (4). Of the 30 car models, we showed these 40-s clips and then measured physiological responses. Participants had 60 s resting states in an interval to observe the patterns. During the resting states, we showed nothing on the display and let them rest. To minimize the order effect, we showed car models randomly for every participant. The environment and protocol of Experiment 1 are as follows (Figs. 7, 8 and 9):

[Participants and Ethical consideration]

Participants (n = 20) were Japanese university students (10 men and 10 women; age: 22.95 ± 1.17). We illustrated to the participants the experiment contents by word of mouth and a document.

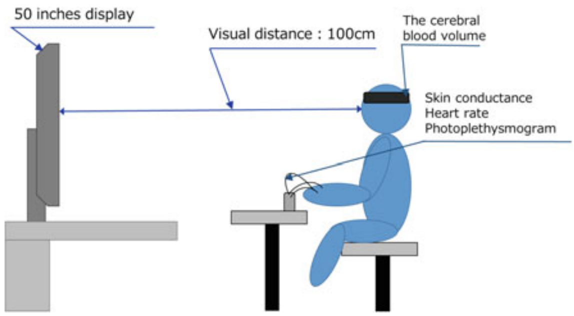


Fig. 7 The environment of the Experiment 1

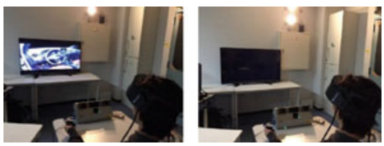


Fig. 8 The image of the Experiment 1

Fig. 9 The protocol of Experiment 1

2.5 Experiment 2: Measuring Subjectivity Evaluation

We let the participants observe 30 images of the interior of cars used in Experiment 1 again and evaluated them subjectively with 25 items of visual impressions ("advanced," "graceful," etc.) selected in 2.2 as targets. In the 30 car models, we selected 1 model as a standard pattern and the others (29 models) as targets. Of all evaluation items, we let participants score them relatively in the range from −100 to +100 comparing with a standard pattern whose mark was set 0 by default.

[Experiment environment, protocol]

In this study, we prepared 2 digital tablet PCs (made by Microsoft) to show images of the interior of cars and a notebook PC to evaluate subjectivity. After the participants were seated, we set tablet PC-I, notebook PC for scoring and tablet PC-II from left (Figs. 10 and 11).

Observing the standard pattern shown at the tablet PC-I, participants observed a target for evaluation shown at tablet PC-II, whose change was equal to that in I and

Fig. 10 The environment of Experiment 2

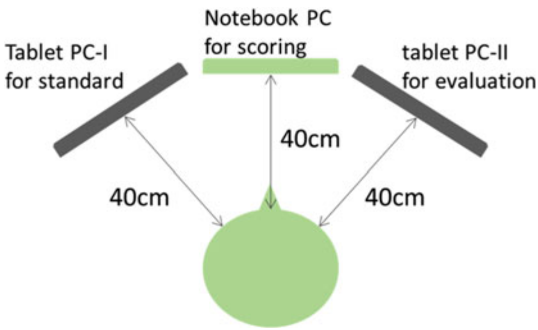


Fig. 11 The image of the Experiment 2

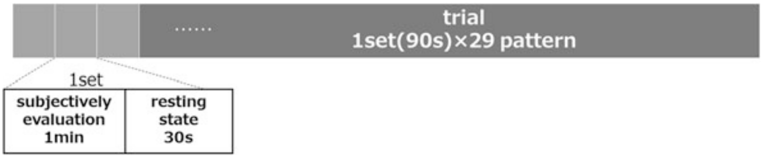


Fig. 12 The protocol for Experiment 2

the scored items in the notebook PC. From 30 cars, we selected the Toyota Camry as a standard pattern because its color was black and was thought to be suitable for comparison (especially for Japanese students). Similar to Experiment 1, slideshows of each pattern lasted for 40 s and they were played on a loop automatically. After evaluation of each pattern, we let the screen remain blank for 30 s, which allowed the participants to rest. To minimize the order effect, we showed car models randomly for every participant (Fig. 12).

[Participant and Ethical consideration]

Participants were the same as those in Experiment 1 (20 university students). We illustrated them the experiment contents by word of mouth and a document.

3 Result

To clarify the relations of physiological responses and subjectivity evaluation, we calculated correlation coefficients for each combination. In particular, after standardizing dates of physiological responses (Experiment 1) and subjectivity evaluation (Experiment 2), we calculated correlation coefficients for each participant.

Considering that we had signaled participants to observe a stimulus 10 s before a pattern started as a value of physiological responses, we used an average of 40 s for observation and subtracted 10 s from the average at rest.

[Correlation analysis] [9]

After calculation correlation coefficients of physiological responses and subjectivity evaluation for every 20 participants, we conducted a correlation analysis to extract combinations suggesting a high correlation as follows:

I. Test of Non-correlations
After having a hypothesis that there is no correlation in a combination, we excluded combinations that could not dismiss the null hypothesis.
II. Test of equivalency of correlation coefficients.
III. We excluded combinations whose equivalency of all participants could not be satisfied.
IV. The final judgment by the point estimation.
V. After conducting a point estimation from the data from 20 participants, we judged the correlation from a general index.

I. Test of Non-correlations

ρ: population correlation coefficient r: sample correlation coefficient
n: number of samples (number of car models) α: significance level (=0.05)
Null hypothesis $H_0 : \rho = 0$
Alternative hypothesis $H_0 : \rho \neq 0$.

Under this null hypothesis, the following formula is established, and r is obtained from the sample of size n.

$$t_0 = t_0 = \frac{|r|\sqrt{n-2}}{\sqrt{1-r^2}} \sim t(n-2, \alpha)$$

Therefore, the conditional expression to dismiss the null hypothesis is as follows:

$$t_0 = \frac{|r|\sqrt{28}}{\sqrt{1-r^2}} > t(28, 0.05) = 1.701$$

$$|r| > 0.3061 \tag{1}$$

In addition, thinking that participants from x out of all 20 satisfies 1

$$\binom{20}{x}(0.05)^x(0.95)^{20-x} < \alpha(= 0.05)$$

$$\therefore x \geq 4 \tag{2}$$

By 1 and 2, in all combinations of physiological responses and subjectivity evaluation, the combination having 4 samples out of 20 participants has a sample correlation coefficient that is bigger than 0.3061 (smaller than −0.3061). This can be dismissed as a non-correlation. It is expected to be a positive correlation (negative correlation). The result of a test of non-correlations is as follows. The Table 2 shows the number of participants who satisfied the conditional expression that a sample correlation coefficient is bigger than 0.3061 (smaller than −0.3061) and combinations that could not meet 4 of 20 are expressed in a blank to exclude the candidates that we should extract.

We have extracted several combinations suggesting a high correlation.

Positive correlation of photoplethysmogram levels and useful, ch4 and friendly, etc.

Negative correlation of ch11 and compact, ch13 and mechanical, etc.

II. Test of an equivalency of correlation coefficients
$1 \leq i \leq k(k$: the number of participants)

ρ: population correlation coefficient r_i: sample correlation coefficient

Table 2 The number of participants to meet the conditional expression

The number of participants satisfying $\lvert r \rvert > 0.3061$	ADVANCED	GRACEFUL	LUXURY	POWERFUL	GENUINE	USEFUL	COMFORTABLE	COLORFUL	NATURAL	PLEASANT	FAMILIAR	ECO	LIGHT	INDIVIDUAL	SIMPLE	SPACIOUS	FASHIONABLE	DELICATE	FLEXIBLE	SPORTY	SAFE	PEACEFUL	COMPACT	MECHANICAL	JUST LIKE MYSELF
skin conductance																									
photoplethysmogram levels						5															4				
instant heart rate																									
ch1																									
ch2																									
ch3																								4	
ch4											5													4	
ch5											4														
ch6																								4	
ch7																									
ch8																									
ch9																									
ch10																									
ch11																							5		
ch12																									
ch13																								6	
ch14								4							4										
ch15														4							4			4	
ch16															4										

n: number of samples (number of car models) α: significance level (=0.05)
Null hypothesis $H_0 : \rho_1 = \rho_2 = \cdots = \rho_{20}$
Alternative hypothesis H_1: All population correlation coefficients may not be right.

Under this null hypothesis, the following formula is established in r obtained from the sample of size n.

$$V = n - 3, \quad Z_i = \frac{1}{2}\ln\frac{1 + r_i}{1 - r_i}$$

$$\chi_0^2 = \sum\nolimits_{i=1}^{k} VZ_i^2 - \frac{\left(\sum_{i=1}^{k} VZ_i\right)^2}{V} \sim \chi^2(k - 1, \alpha) \tag{3}$$

According to 3, in all combinations of physiological responses and subjectivity evaluations, the combination satisfies:

$$\chi_0^2 > 30.1$$

This is not equivalency of correlation coefficients, and we excluded it from the candidate we should extract (Table 3).

For example, the positive correlation of photoplethysmogram and useful could not satisfy an equivalency of a correlation coefficient; hence, it is excluded from the candidate we should extract.

III. The final judgment by the point estimation
$1 \leq i \leq k$ (k: number of participants)

ρ: population correlation coefficient r_i: sample correlation coefficient
n: number of samples (number of car models) α: significance level (=0.05)

Table 3 Combinations satisfying the test of an equivalency

Combinations satisfying |r|>0.3061 & equivalency	ADVANCED	GRACEFUL	LUXURY	POWERFUL	GENUINE	USEFUL	COMFORTABLE	COLORFUL	NATURAL	PLEASANT	FAMILIAR	ECO	LIGHT	INDIVIDUAL	SIMPLE	SPACIOUS	FASHIONABLE	DELICATE	FLEXIBLE	SPORTY	SAFE	PEACEFUL	COMPACT	MECHANICAL	JUST LIKE MYSELF
skin conductance																									
photoplethysmogram levels																									
instant heart rate																									
ch1																									
ch2																									
ch3																									
ch4																									
ch5																									
ch6																									
ch7																									
ch8																									
ch9																									
ch10																									
ch11																									
ch12																									
ch13																									
ch14																									
ch15																									
ch16																									

$$Z_m = \frac{\sum_{i=1}^{k} V_i Z_i}{\sum_{i=1}^{k} V_I}$$

$$r^* = \frac{exp(2Z_m) - 1}{exp(2Z_m) + 1}$$

The point estimation level can be calculated by this formula. In addition, it is said that if the absolute value of this point estimation level is larger than 0.20, the combination has little correlation. Therefore in all combinations of physiological responses and subjectivity evaluation, the combination satisfying

$$|r^*| \geq 0.20$$

is thought to have a high correlation (Table 4).

The point estimation level of ch4 and friendly was 0.21.
The point estimation level of ch13 and mechanical was −0.21.
Hence, these combinations satisfy the conditional express and are correlated.

Table 4 The result of the point estimation

The point estimation	ADVANCED	GRACEFUL	LUXURY	POWERFUL	GENUINE	USEFUL	COMFORTABLE	COLORFUL	NATURAL	PLEASANT	FAMILIAR	ECO	LIGHT	INDIVIDUAL	SIMPLE	SPACIOUS	FASHIONABLE	DELICATE	FLEXIBLE	SPORTY	SAFE	PEACEFUL	COMPACT	MECHANICAL	JUST LIKE MYSELF
skin conductance																									
photoplethysmogram levels																									
instant heart rate																									
ch1																									
ch2																									
ch3																								-0.07	
ch4											0.21													-0.16	
ch5											0.08														
ch6																								-0.09	
ch7																									
ch8																									
ch9																									
ch10																									
ch11																							-0.10		
ch12																									
ch13																								-0.21	
ch14								0.06							0.13										
ch15																								-0.13	
ch16															0.15										

4 Consideration

As a result of the correlation analysis, we could find a positive correlation of ch4 and "familiarity" and a negative correlation of ch13 and "mechanical."

- Positive correlation of ch4 and "familiarity"
  Because ch4 belongs to MPFC that is related to sympathy [10], there is not the sense of incongruity. Therefore, it can be said that this result is valid.
- Negative correlation of ch13 and "mechanical"
  Ch13 belongs to MPFC that is related to sympathy as well [10]. Because "mechanical" is an impression item meaning that movement is like not human but a machine, it can be thought to not contradict ch13 activation and is related to low "familiarity."

In addition, the positive correlation of ch4 and "familiarity" is a combination whose significance of the correlation is suggested in the preceding study using 3DCG images as targets. Thus, this combination's reliability has increased.

5 Summary

In this study, we experimentally searched for indices to detect impressions of appearance using cars as targets. In particular, we conducted 2 experiments: measuring physiological responses and subjectivity evaluation using images of interior of 30 cars at home and abroad as a stimulus. We calculated correlation coefficients of physiological responses and visual impressions and found several data to objectively evaluate visual impressions. Although we could not find physiological responses to support for all visual impressions that we prepared for in this study, we have obtained two results: the positive correlation of ch4 belonging to MPFC and "familiarity" and the negative correlation of ch13 also belonging to MPFC and "mechanical." In these results, the positive correlation of ch4 and "familiarity" was found in the preceding study using 3DCG images as targets. Thus, this combination's reliability has increased. Although we used cars as targets in this study, it is possible to investigate combinations of physiological responses and visual impressions of another product adopting the same approach. If the versatility of the result continues to increases, it can meet the requirements of manufacturers to objectively evaluate impressions and is expected to create an objective evaluation.

References

1. An education apparatus editing committee: An Industrial Education Apparatus System Manual. JUS Press (1972)
2. Nagashima, T., Kubo, H.: The Sensitivity and Information for the New Manufacturing. Morikita Shuppan Co., Ltd (2007)
3. Inoue, M., Kobayashi, T.: The research domain and scale construction of adjective-pairs in a semantic differential method in Japan. Jpn. J. Educ. Psychol. (1985)
4. Muraji, S. Nakanishi, M.: A product design process to evaluate users' intrinsic satisfaction—designing center consoles in cars. Graduation Thesis in Keio University (2014)
5. Murai, T.: Aberrant social behaviors after brain injury. Department of Neuropsychiatry, Graduate School of Medicine, Kyoto University. 54 Shogoin-Kawaharacho, Kyoto 606–8507, Japan (2010)
6. Levesque, J., Eugene, F., Joanette, Y.: Neural circuitry underlying voluntary suppression of sadness. Biol. Psychiatry **53**, 502–510 (2003)
7. Picard., R. W.: Affective Computing. MIT Press (2000)
8. Lang, P.J.: The emotion probe. Am. Psychol. **50**, 372–385 (1995)
9. Mizumoto, A., Takeuchi, O.: Basics and considerations for reporting effect sizes in research papers. Kansai Engl Educ Soc Bull **31**, 57–66 (2008)
10. Arita, H.: Tears and stress relaxation. Folia Pharmacol. Jpn. **129**, 99–103 (2007)

A Method to Evaluate Consumer Desire for Continued Product Usage: Incorporation of the Method in the Automobile Design Process

Tadashi Yura, Tsuneyuki Yamamoto, Naoki Kamiya and Miwa Nakanishi

Abstract Consumers expect mature products such as cars to provide value in addition to conventional features such as safety and usability. Hence, introducing methods to evaluate consumer perceptions of the worth of new features during the design process benefits manufacturers. Consequently, increasing attention has been recently focused on user experience (UX). This project examined three aspects of UX, namely, the "desire to try using" during an encounter, the "goodness of using," and the "desire to continue to use" after the initial usage. Then, a method for introducing these aspects into the product design process was developed. Thus, the factors that influence user desire to continue the product usage were obtained. The relation between the user requirements and the design elements was examined, and a method that quantitatively evaluates user desires based on the design elements during the design process was proposed.

Keywords User experience · Attachment · Product design · Cars

1 Introduction

Consumers demand that besides conventional features such as safety and usability, mature products such as cars should provide additional value. Hence, methods to evaluate the perception of the worth of new features by consumers during the design process benefits manufacturers. Consequently, increasing attention has recently been focused on user experience (UX). Microsoft (Windows User Experience Guidelines [1]) and Apple (Apple User Experience Guidelines [2]) first proposed the definition of UX in accordance with ISO9241-210 [3]. In general, UX is a concept that involves the valuation of the product itself and the compre-

T. Yura (✉) · M. Nakanishi
Graduate School of Science and Technology, Keio University, Yokohama, Japan
e-mail: tadashiyu0617007@z2.keio.jp

T. Yamamoto · N. Kamiya
Tokai Rika Co., Ltd., Niwa, Japan

M. Soares et al. (eds.), *Advances in Ergonomics Modeling, Usability & Special Populations*, Advances in Intelligent Systems and Computing 486,
DOI 10.1007/978-3-319-41685-4_56

hensive value of the experience obtained in the course of interaction with the product.

Nakanishi divided the interactions between users and products into three phases in a time series, and suggested that in order to improve UX, the user should be in a "want to use" phase, or a "comfortable using" phase, or a "want to continue to use" phase [4]. In this paper, three aspects of UX were studied from a time series viewpoint. These aspects are the "desire to try using" during a product encounter, the "goodness of using" while using the products, and the "desire to continue to use" after the initial usage. Then, a method for introducing these aspects into the product design process was developed. Experiments revealed the requirements of the "desire to try using" and the "goodness of using" aspects. The design elements contributing to these requirements were examined, and a three-layer model representing the relation between the elements was developed. Then, each link in the model was formulated to quantitatively estimate the fore-mentioned aspects from the design elements with respect to on-vehicle product [5, 6]. In this paper, we evaluated the factors that influence user desire to continue product usage. The relation between the user desire, the requirements of the user desire, and the design elements was investigated. A method that quantitatively evaluates user desire based on the design elements was developed.

2 Extraction and Structure of Requirements Contributing to the Desire to Continue Product Usage and Design Elements

First, a root-cause analysis survey was conducted to reveal the requirements for the desire to continue product usage and the design elements contributing to these requirements. The survey also enabled the structuring of the model framework.

2.1 Method

The user desire to continue using a product is composed of several requirements, which in turn comprise several design elements. Figure 1 shows the hierarchical structure of the design elements used as a framework for this study. A root-cause analysis survey was conducted to reveal and structure the framework.

Figure 2 shows the factors included in the root-cause analysis survey. The survey was conducted with 54 subjects of ages ranging 20–50 years. It included all the products that the subjects willingly continued to use.

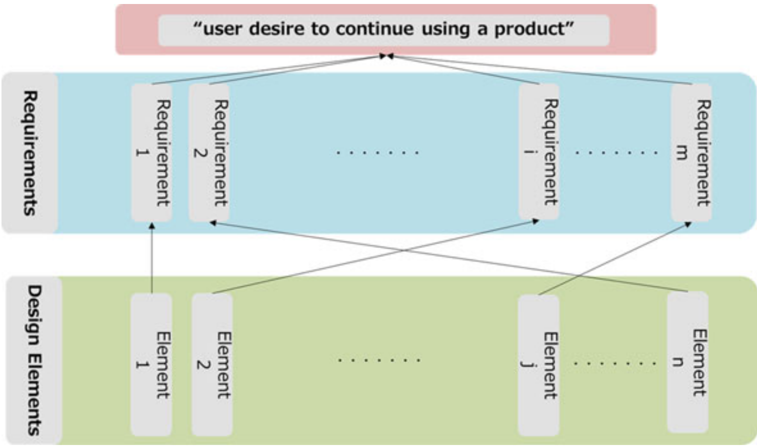


Fig. 1 The study framework

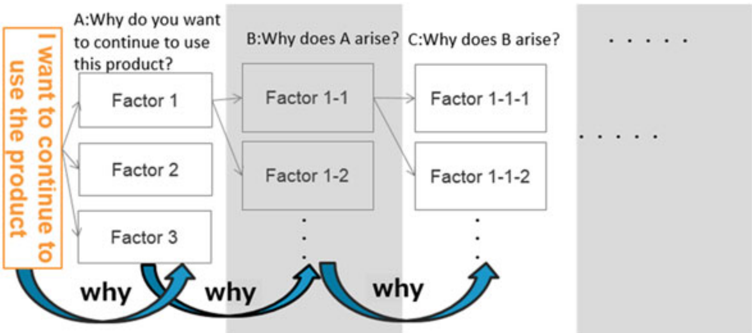


Fig. 2 Factors extracted by the root-cause analysis survey

The survey had high flexibility of descriptive contents. Hence, the 615 factors extracted from the survey were grouped into three phases, namely, the "characteristics of product", the "meaning of product for users," and the "feeling related to user desire to continue product usage" phases. Figure 3 shows a method of grouping the factors.

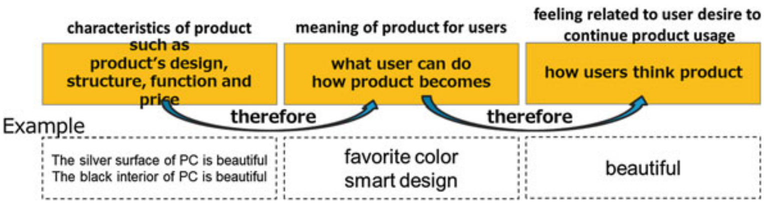


Fig. 3 A method of the factors

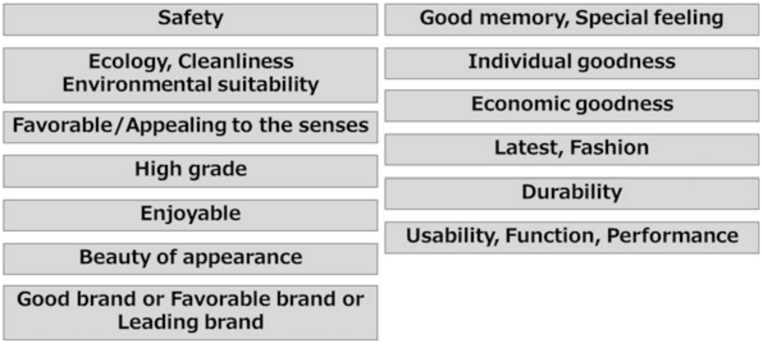


Fig. 4 Requirements for the desire to continue product usage

2.2 *Ethical Considerations*

The experiment was explained orally to the subjects and their informed consent was obtained. The data collection and analysis occurred within the university.

2.3 *Results*

In the study, the KJ method was used to group the 615 "meaning of product for users" factors into 13 requirements for the desire to continue product usage. Figure 4 depicts the 13 requirements. Then, the 615 "characteristics of product" factors were grouped into 68 design elements, which included "beautiful color" and "existence of memories such as pictures". Table 1 shows the design elements.

The relation between the design elements and the desire to continue product usage was structured as a three-layer model, as shown in Fig. 5. The top layer indicated the desire to continue product usage, the middle layer indicated the 13 requirements of the desire, and the bottom layer denoted the design elements. The three-layer model was used as the framework of the evaluation model.

3 Quantification of the Structural Model

The subjects answered questions regarding the difference between (a) the products they continued using (or those they wanted to continue using) and (b) the products they had stopped using (or those they did not want to continue using but they continued to use reluctantly). Then, the structural model was quantified.

Table 1 Design elements

Requirements	Design elements	Requirements	Design elements
Safety	Safe brand/maker※1	Latest, fashion	Current/fashionable color
	Safe function/performance		Current/fashionable shape/size
Good memory special feeling	Special way to obtain		Current/fashionable brand/maker※8
	Maintenances※2		Current function/performance
	Customizing/processing※3		New products
	I had wanted it for a long time		Products used by many people
	High price※4		Current expression/screen
	I have used it for a long time/I have used it frequently		Current/fashionable operation device
	Conservation of memory	Enjoyable	Full-blown products
	Good experience of use		Enjoyment of function
Ecology, cleanliness environmental suitability	Ecological function/performance		Maintenances※2
	Quiet sound		Shape/size fitting the body※6
	Cleanliness		User-friendly weight/light※9
Individual goodness	Individual and good color		Explicit expression/method※10
	Individual and good shape/size		User-friendly operation device※11
	Individual and good material		Easy method/procedure※12
	Individual and good brand/maker※5	Durability	Shape/size generating strength
	Individual and good function/performance		Weight generating strength
	Individual and good description/ornament		Strong material
	Customizing/processing※3		Tough function/performance
	Limited item/hand-made article		High durability from external influence
	Change by long time use	Beauty of appearance	Beautiful and cool color
Favorable/appealing to the senses	Shape/size fitting the body※6		Beautiful and cool shape/size
	Just right weight		Beautiful and cool material
	Good lightness for the body		Beautiful and cool logo/mark

(continued)

Table 1 (continued)

Requirements	Design elements	Requirements	Design elements
	Sound is good aurally		Beautiful and cool letter/icon
	Expression/display is good visually		Simple description/ornament
	Good touch for the body		Beautiful and cool light/brightness
Economic goodness	Good discount service/Good free service		Beautiful and cool screen
	Economic function/performance	Usability, function, performance	Shape/size fitting the body※6
High grade	Color presenting an image of high-quality		Shape/size generating easiness of carrying out and putting in storage
	Shape/size presenting an image of high-quality		User-friendly weight/light※9
	Material presenting an image of high-quality		Convenience of function
	Brand/Maker presenting an image of high-quality※7		Sufficient performance
	Performance presenting an image of high-quality		Explicit expression/method※10
	Description/Ornament presenting an image of high-quality		User-friendly operation device※11
	High price※4		Easy method/procedure※12
	Products purchased in high-class shop	Good brand or Favorable brand or Leading brand	Safe brand and maker※1
			Individual and good brand/maker※5
			Brand/Maker presenting an image of high-quality※7
			Current/Fashionable brand/maker※8
			Popular brand/maker
			Brand/maker of high-quality

※ Common design elements

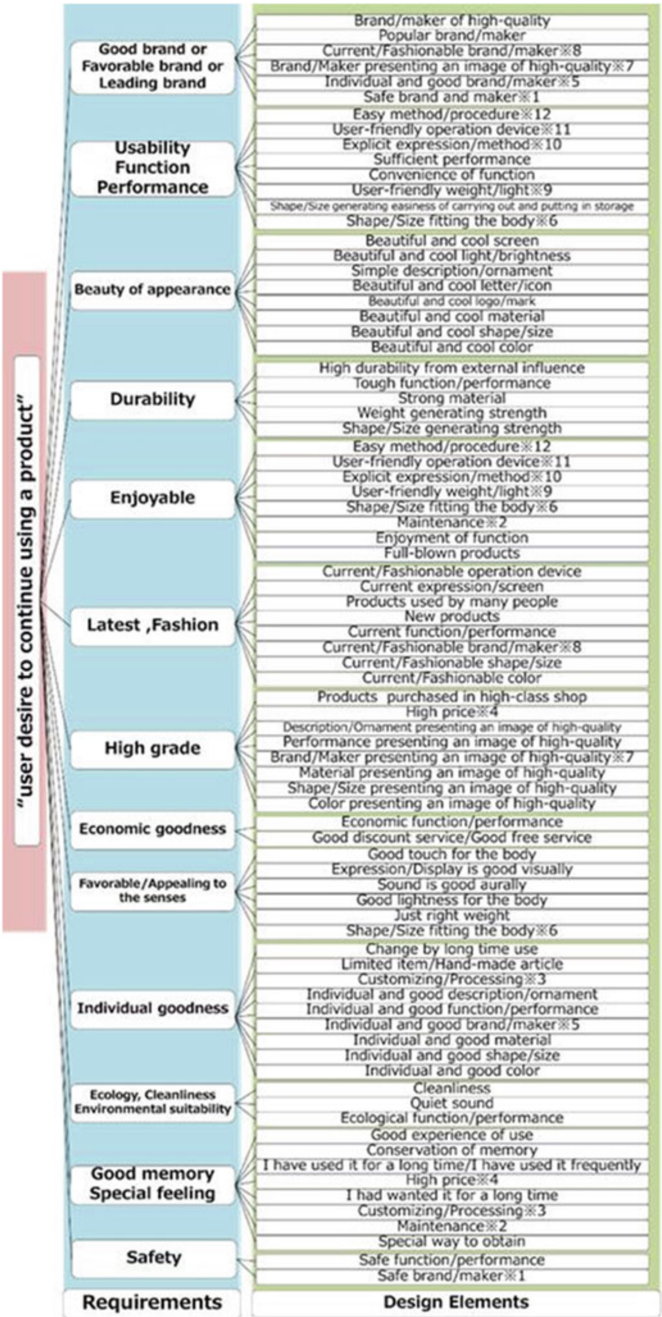


Fig. 5 The framework of the evaluation model

3.1 Method

To quantify the model, subjects were questioned regarding the difference between (a) products they continued using (or those they wanted to continue using) and (b) products they stopped using (or those they did not want to continue using but they reluctantly continued to use). For each product type (a and b), the subjects scored the 13 requirements on a range of 0–100 using the VAS (Visual Analog Scale) method and answered as to whether the 80 design elements corresponded. For each product type, it was hypothesized that the relation between the design elements in the bottom layer and requirements contributing to the desire to continue product usage in the middle layer was different.

In addition, the relation between the requirements in the middle layer and the desire to continue product usage in the top layer was considered to be different. Hence, the products were classified from two viewpoints, namely, the necessity of operation viewpoint and carrying out viewpoint.

Then, the products selected by the answers were restricted to products that needed operation and are carried out, such as cars. This survey included 40 subjects of age ranging from the 20s to the 50s. The balance of gender and generation was also taken into account.

The subjects were questioned about their profile, product details, and the score for each of the 13 requirements on a scale of 0–100 in the first sheet. Then, the subjects answered as to whether 80 design elements corresponded in the second sheet. Figure 6 show the first and second sheets, respectively.

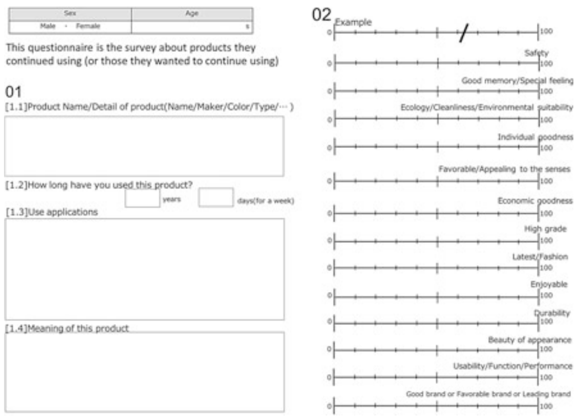


Fig. 6 The first sheet of the survey

3.2 Ethical Considerations

The experiment was orally explained to the subjects and their informed consent was secured. The data collection took place within university premises.

3.3 Results

Quantification of the impact of the requirements for the desire to continue product usage on the "desire to continue to use"

A logistic regression analysis was used to analyze and formulate the relation between the requirements in the middle layer and the desire to continue product usage in the top layer. This was used to calculate the probability of the desire. The objective variable involved whether the users willingly continued product usage. The explanatory variable was the score of the requirements. Table 2 shows the coefficient of determination and the partial regression coefficients. According to the results, for products that required operation and are carried out, such as cars, the "goodness of sensibility" requirement had the most impact on the "desire to continue to use".

Quantification of the impact of design elements on requirements for the desire to continue product usage

The relation between the design elements in the bottom layer and requirements contributing to the desire to continue product usage in the middle layer was analyzed and formulated by using quantification theory type-I. The objective variable was the score of the requirements. The explanatory variable indicated whether the design elements corresponded. Quantification theory type-I was conducted on 7 requirements given in Table 2. Table 3 shows the category scores, ranges, and coefficients of determination. The results revealed the magnitude of impact from each design element on the requirements for the desire to continue product usage. Thus, the impact of important design elements on the requirements could be investigated.

Table 2 Coefficient of determination and partial regression coefficients

Requirements	Partial regression coefficient
Good memory, special feeling	0.0076
Ecology, cleanliness, environmental suitability	0.0052
Favorable/appealing to the senses	0.0374
Latest, fashion	0.0006
Durability	0.0026
Beauty of appearance	0.0341
Usability, function, performance	0.0598
Constant term	−10.0998
Coefficient of determination	0.4426

Table 3 Category scores, ranges, and coefficients of determination

	Design elements	Category	Category scores	Range
Good memory special feeling	Maintenance	×	−1.0231	3.3676
		○	2.3445	
	I had wanted it for a long time	×	−1.3128	6.1008
		○	4.7880	
	High price	×	−0.5964	1.5706
		○	0.9742	
	I have used it for a long time/I have used it frequently	×	−3.2669	5.2671
		○	2.0001	
	Conservation of memory	×	−2.7654	7.0474
		○	4.2819	
	Good experience of use	×	−3.7017	14.6215
		○	10.9199	
	Constant term	60.2278		
	Coefficient of determination	0.2096		
Ecology, cleanliness, environmental suitability	Ecological function/performance	×	−4.1202	36.1661
		○	32.0459	
	Quiet sound	×	−1.6831	5.1140
		○	3.4309	
	Constant term	50.2278		
	Coefficient of determination	0.3625		
Favorable/appealing to the senses	Shape/size fitting the body	×	−7.8585	13.7961
		○	5.9376	
	Just right weight	×	−2.5857	7.2952
		○	4.7096	
	Good lightness for the body	×	−0.6439	2.2116
		○	1.5677	
	Sound is good aurally	×	−0.7821	4.7528
		○	3.9707	
	Expression/display is good visually	×	−0.1203	0.3803
		○	0.2599	
	Good touch for the body	×	−4.5914	10.9916
		○	6.4002	
	Constant term	65.5823		
	Coefficient of determination	0.3266		

(continued)

Table 3 (continued)

	Design elements	Category	Category scores	Range
Latest, fashion	Current/fashionable shape/size	×	−0.0820	0.4985
		○	0.4165	
	Current/fashionable brand/maker	×	−4.3318	16.2958
		○	11.9640	
	Current function/performance	×	−1.9594	12.8994
		○	10.9400	
	New products	×	−1.3494	9.6912
		○	8.3418	
	Products used by many people	×	−0.2530	1.1759
		○	0.9228	
	Current expression/screen	×	−1.0587	7.6035
		○	6.5448	
	Current/fashionable operation device	×	−0.6197	4.4506
		○	3.8309	
	Constant term	52.8987		
	Coefficient of determination	0.3524		
Durability	Shape/size generating strength	×	−1.8072	7.9318
		○	6.1246	
	Weight generating strength	×	−0.8455	4.1748
		○	3.3293	
	Strong material	×	−2.8049	9.6341
		○	6.8292	
	Tough function/performance	×	−2.9844	9.0681
		○	6.0837	
	Constant term	63.8734		
	Coefficient of determination	0.2067		
Beauty of appearance	Beautiful and cool color	×	−13.0440	21.0302
		○	7.9861	
	Beautiful and cool shape/size	×	−6.4252	13.3577
		○	6.9325	
	Beautiful and cool material	×	−1.3723	3.1887
		○	1.8163	
	Beautiful and cool logo/mark	×	−1.1649	4.0012
		○	2.8363	
	Beautiful and cool light/brightness	×	−0.7793	4.1044
		○	3.3251	
	Beautiful and cool screen	×	−0.0097	0.0348
		○	0.0251	
	Constant term	67.5570		
	Coefficient of determination	0.5036		

(continued)

Table 3 (continued)

	Design elements	Category	Category scores	Range
Usability, function, performance	Shape/size fitting the body	×	−3.3823	5.9377
		○	2.5555	
	User-friendly weight/light	×	−1.8910	4.1496
		○	2.2587	
	Convenience of function	×	−1.9643	8.6211
		○	6.6568	
	Sufficient performance	×	−0.8421	1.7058
		○	0.8637	
	Explicit expression/method	×	−0.0602	0.1485
		○	0.0884	
	User-friendly operation device	×	−4.1055	11.5833
		○	7.4778	
	Easy method/procedure	×	−5.7473	10.0897
		○	4.3424	
	Constant term	68.5823		
	Coefficient of determination	0.2919		

Models to estimate the "desire to continue to use" from design elements

The two-step quantification process that has been described above was conducted. The process involved quantifying the "desire to continue to use" from the requirements for the desire to continue product usage. It also involved the process of quantifying the requirements from each design element. Then, the model that estimated the "desire to continue to use" was constructed from the design elements, by targeting products that required the operation and are carried out, such as cars.

According to the model, "Usability, Function, Performance" was the requirement with the most influence on the "desire to continue to use." The design elements with the most influence on this requirement were "User-friendly operation device" and "Easy method/procedure." Therefore, these design elements had the most influence on the "desire to continue to use."

4 Verification of the Precision of the Model

4.1 Method

The subjects answered questions regarding the design elements of their cars and the extent of their desire to continue using the cars (measured values of their desire to continue using the cars). This model was used to compare the estimated values of

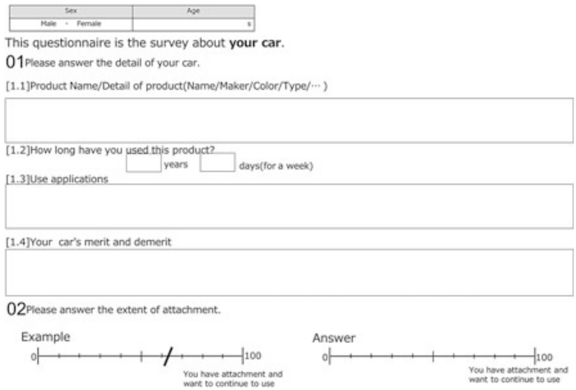


Fig. 7 The first sheet

the desire to continue product usage. The values were measured to verify the precision of the model. The subjects were questioned about their profiles, the details of their cars, and the extent of their desire to continue using their cars (that is, the measured values of their desire to continue using the cars) in the first sheet. Then, the subjects were questioned regarding the design elements of their cars in the second sheet. Figure 7 shows the first sheet. The survey was conducted for twenty subjects with age groups ranging from the 20s to the 50s.

4.2 Ethical Considerations

The experiment was orally explained to the subjects and their informed consent was secured. Then, the data collection and analysis took place within the university premises.

4.3 Result

Figure 8 shows the relationship between the estimated values of the desire to continue product usage and measured values. The slope of the regression equation was 0.75. The coefficient of determination was 0.70.

Therefore, it was confirmed that the model estimated the magnitude of "the desire to continue to use" with high accuracy.

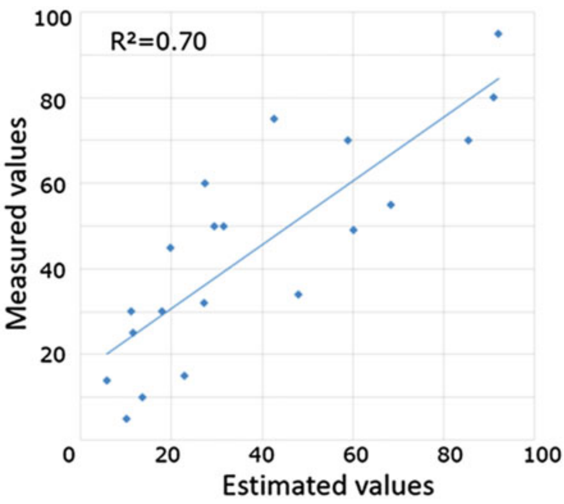


Fig. 8 Relationship between the estimated value and the measured values

5 Applicability of the Model

The model constructed in this study has two potential applications from a practical viewpoint. First, the model can be used in a bottom-up analysis. The model enables the estimation of the consumer requirement that produces a certain magnitude of the "desire to continue to use" when people select requirements in the design process of products that require operation and are carried out, such as cars. The selection of ideas in the design process by designers is supported by the usage of the model to quantitatively evaluate the "desire to continue to use".

Second, the model can be used in a top-down analysis.

For example, if a product with a larger the "desire to continue to use" has to be designed, important design elements with the highest and lowest impacts on the desire can be evaluated.

6 Conclusion

In the study, the relationship between user desire to continue to use and the design elements was structured and formulated to construct a model. The process targeted products that requires operation and are carried out, such as cars. For the evaluation of the model, we used a method to estimate the user desire to continue to use products from the design elements and to quantitatively evaluate the products. In addition, the paper proposed using the model in the processing design scenario. The study targeted products that required operation and are carried out, such as cars. Similarly, the models targeting other products can also be formulated. In addition to conventional features such as safety and usability of the products, by introducing the three aspects of UX—the “desire to try using” during a product encounter, the “goodness of using” while using the products, and the “desire to continue to use” after the initial usage in the product design process—new values can be added to the products.

References

1. Microsoft Windows User Experience Guidelines: Retrieved from http://msdn.microsoft.com/ja-jp/library/aa511258.aspx. Accessed 16 Jan 2013
2. Apple User Experience Guidelines: Retrieved from http://developer.apple.com/library/mac/#documentation/userexperience/conceptual/applehiguidelines/UEGuidelines/UEGuidelines.html. Accessed 15 Jan 2013
3. ISO9241-11: Ergonomic requirements for office work with visual display terminals. Part 11: Guidance on Usability (1998)
4. Nakanishi, M.: Strategic approach toward UX design based on the concept of PSF. J. Hum. Life Eng. **13**(1), 67–70 (2012)
5. Muraji, S., Nakanishi, M. A.: Product design process to evaluate users’ intrinsic satisfaction—designing center consoles in cars. Graduation thesis in Keio University (2014)
6. Ohashi, H.: The study about the relationship between switch’s design elements and the goodness of using: quantitative modeling based on the experiment and the statistical analysis. Graduation thesis in Keio University (2013)

Design Requirements to Reduce Discomfort in Window Viewing: Study on Increasing Degrees of Freedom of Car-Body Shape

Kazuki Fujita and Miwa Nakanishi

Abstract Motion sickness is caused by the information differences between the vestibular, visual, and bodily senses. Window curvature and sight blurring are considered to influence eyesight information. This study experimentally investigated the influence of motion sickness by window curvature and sight blurring changes in the response to multiple combinations of conditions. The result indicated that a view from a car window with a vertical wave on the window surface was likely to cause motion sickness. Conversely, visual distortion in the horizontal direction could be acceptable to passengers. The study also proposed the minimum design requirements for car-body shape based on the results.

Keywords Motion sickness · Car design · Window viewing

1 Introduction

Over the past several years, cars are indispensable in daily life and a wide variety of cars are produced and sold all over the world. In the first decade of the 21st century, major changes occurred in the body design of the car.

More specifically, the changes included IT adoption and eco-design modeling to introduce a package with a high-efficiency utility space, high-precision, and high-efficiency design development [1]. The highly efficient package results in increased car height, and allows the place where the engine is mounted to become more compact. As a result, small cars create significant space at the foot area and hence they are spacious for their given size. This change allows the driver to have a higher viewpoint. The position and the angle of the on-vehicle meter were studied

K. Fujita (✉) · M. Nakanishi
Department of Administration Engineering, Keio University,
Yokohama 223-8522, Kanagawa, Japan
e-mail: abacus.kazuki.fujita@gmail.com

M. Nakanishi
e-mail: miwa_nakanishi@ae.keio.ac.jp

M. Soares et al. (eds.), *Advances in Ergonomics Modeling, Usability & Special Populations*, Advances in Intelligent Systems and Computing 486,
DOI 10.1007/978-3-319-41685-4_57

and implemented to provide easier access for a driver with the new viewpoint. The component shape can be confirmed by 3D rendering without creating a prototype with design development by IT adoption. Additionally, it is easier and more efficient to share the information between departments and to develop the cars. The modeling of eco-design is an important mission for current car design. Currently, various systems such as electric vehicles that do not rely solely on fossil fuels are in practical use. A future issue for the current vehicle body design involves proposing a new design that satisfies the concept that suits life in the future.

These changes focus on the car body contents and cars were adjusted and developed to match the lifestyles and physical characteristics of individuals. Furthermore, customer demands for automotives also diversified to include the ease of decision-making while driving, decreased motion sickness possibilities, and seat comfort.

Therefore, considerable flexibility in the car body design provides more ease in designing a good product or service to design a car body that satisfies a variety of lifestyles, human characteristics, and customer needs. Above all, the window glass considerably influences the degree of freedom of the car body design. The body shape varies greatly between various vehicles such as typical small cars and racing cars depending on the car shape and the window glass curvature.

However, the shape or window glass curvature cannot be changed beyond a certain point as it could cause a deterioration of the view through the window. A product standard for the driver visibility of the automotive window glass exists, and hence it is possible to derive the constraints. However, there is no standard for visibility for the passenger in the rear seat.

Therefore, this study focused on investigating the influences of window curvature and sight blurring on the change in motion sickness change under different conditions, and to explore the minimum design requirements.

According to sensory conflict theory [2], motion sickness is caused by differences in the information provided by multiple organs. This includes vestibular and visual information, or the contradiction between the sensory information memory from past experience and the actually perceived sensory information. The information from eyesight is also considered to be affected by the automobile window glass, the warp of the window (curvature), and the sight blurring by window deformation (variation in glass thickness) are also considered as factors affecting the visibility of the window.

This paper examined the influences of the warp window and deformation changes in response to multiple combinations of conditions on motion sickness.

However, it was very difficult to change two elements in the actual experiment window. Thus, the paper centered on visually induced motion sickness (VIMS) because it had a developing mechanism similar to car sickness (motion sickness). VIMS is a condition similar to motion sickness, and it includes the development of symptoms such as vertigo, sweating, sleepiness, increase in saliva, facial pallor, epigastric distress, nausea or vomiting when videos involving frequent motion are viewed [3]. Visual information in daily lives is accompanied by information from other organs. VIMS is considered to happen because the information from senses such as vestibular information does not accompany visual information that is provided. Therefore, VIMS results in sickness because of the gap between the senses and the actual information, and hence it has the same mechanism as motion sickness [4]. Accordingly, the experiment with two elements was performed by varying the change in the window warp and the video deformation.

2 Introduction

2.1 Experimental Outline

The window of changing the warp (curvature) and the deformation (variation in thickness of glass) was reproduced by using 3DCG software Cinema4D R16 (MAXON, Inc.). The landscape from the rear seat was simulated to create 15 videos. The videos included several brick blocks and buildings with surface grid patterns to make it easier for the participants to notice the change in the window.

A participant received a description of the experiment, which was attached to the measuring instrument. Then, the subjects rested for two minutes with their eyes closed in order to measure the physiological responses in the normal condition. Then, the subjects watched the video for three minutes, and orally answered the simulation sickness questionnaire (SSQ) [5]. The subjects then rested for a minute with their eyes closed in order to remove the influence of motion sickness from the previous video. This number of times this sequence of three movements (video viewing, SSQ, resting) was viewed equaled the number of experimental conditions. The presentation order of the video was random to minimize order effects. The flow of the experiment is shown in Fig. 1.

2.2 Experimental Environment

Figure 2 shows a schematic illustration of the experimental apparatus and the arrangement of the participant. The average interior luminance during the experiment was 11.8 1×. The participant's heart and right arm were adjusted at the same height by placing the table to continuously measure blood pressure.

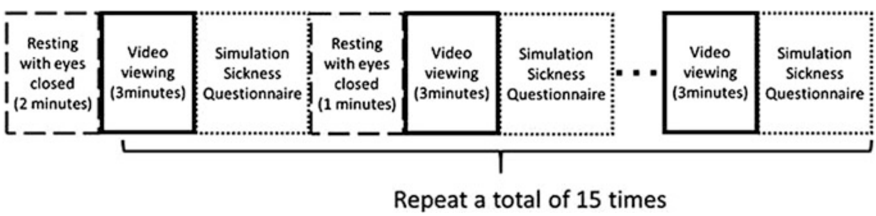


Fig. 1 Flow of the experiment

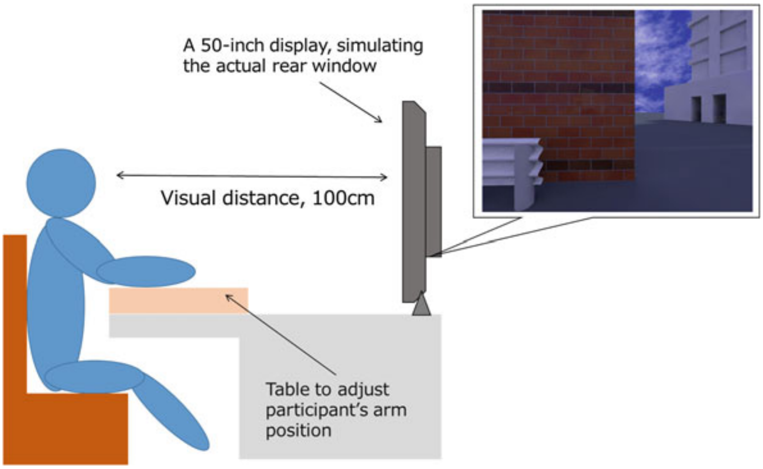


Fig. 2 The experimental environment

2.3 Participants

Twenty-two men (average age: 21.95 ± 1.77 (SD) years; range: 20–25 years) participated in the study. All participants refrained from consuming caffeine and alcohol on the previous day of the experiment, and they ate their last meal four hours prior to the experiment to facilitate electrogastrogram measurements.

2.4 Experimental Conditions

The following experimental conditions were established: three radii of curvature for the window ["no warp(radius of curvature 0 cm)," "small warp(radius of curvature 600 cm)," "large warp(radius of curvature 300 cm)"] as an indicator of the window of warp, and five patterns of window thickness variation ["uniform thickness (5 mm thick homogeneous)," "non-uniform thickness: asymmetric horizontal wave (the squared sine wave with an amplitude of 0.1 mm in horizontal direction on one side of the 5 mm thick window)," "non-uniform thickness: asymmetric vertical wave(the squared sine wave with an amplitude of 0.1 mm in vertical direction on one side of the 5 mm thick window)," "non-uniform thickness: symmetric horizontal wave(the squared sine wave with an amplitude of 0.1 mm in horizontal direction on both sides of the 5 mm thick window)," "non-uniform thickness: symmetric vertical wave(the squared sine wave with an amplitude of 0.1 mm in vertical direction on both sides of the 5 mm thick window)"]as an indicator of the window of deformation. Figure 3 shows an image of the experimental conditions.

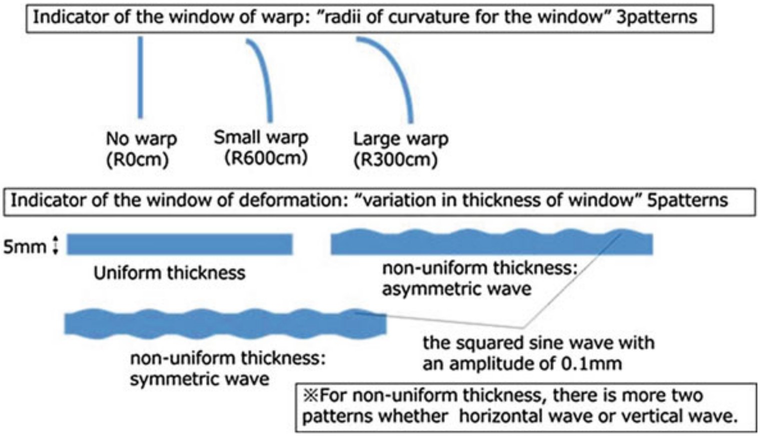


Fig. 3 Image of the experimental conditions

2.5 *Measurements*

The subjective evaluation value and the physiological response related to the motion sickness were measured. The simulation sickness questionnaire (SSQ) was selected for the subjective evaluation [5]. The SSQ was composed of 16 symptoms that are considered to be representative of the state of the simulator sickness. Participants choose a response ranging from 0 (None), 1(Slight), 2(Moderate), and 3(Severe). As each symptom fell under one or more categories of the motion sickness subscale (Table 1), it was possible to calculate the respective total scores

Table 1 Simulation sickness questionnaire [5]

	Symptoms	Subsoles		
		Nauses	Oculo-motor	Distorientation
1	General discomfort	○	○	
2	Fatigue		○	
3	Headache		○	
4	Eyestrain		○	
5	Difficulty focusing		○	○
6	Increased salivation	○		
7	Seating	○		
8	Nausea	○		○
9	Difficulty concentrating	○		
10	Fullness of head			○
11	Blurred vision			○
12	Dizzy(eyes open)		○	○
13	Dizzy(eyes closed)			○
14	Vertigo			○
15	Stomach awareness	○		
16	Burping	○		

for each of the subscales. Further, the weight given to each of the subscales was multiplied to determine the total score of motion sickness. If the score exceeded 100, it implied that a respondent had motion sickness.

Five indices were measured for the psychological response. They included skin conductance response, heart rate (photoplethysmogram levels), continuous blood pressure values, electrogastrogram measurements, and respiratory rates and patterns. The five indices were normalized across the individuals.

2.6 Ethics

All participants provided their informed consent. Data were encrypted to prevent identification.

3 Result

3.1 Subjective Evaluation

SSQ total scores were analyzed by a two-way factorial analysis of variance. The results indicated that the deformation effect was significant, $F(4,315) = 9.7676$, $p < 0.01$, and there was no interaction between warp and deformation. Under the deformation conditions, the window of non-uniform thickness (symmetric vertical wave) was significantly different from that of the other deformations. Figure 4 shows the average SSQ total score for each deformation. This result indicated that viewing from the window of non-uniform thickness (symmetric vertical wave) was more likely than other deformations to cause motion sickness.

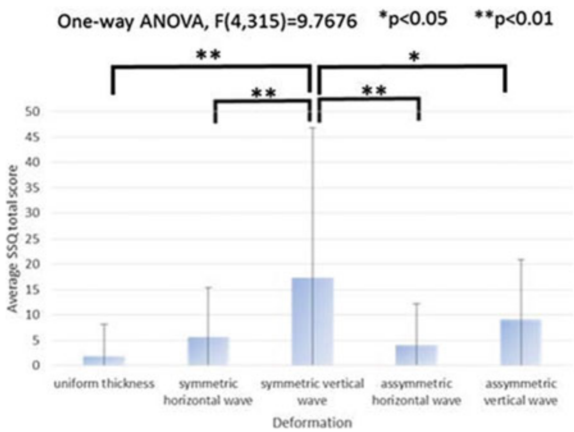


Fig. 4 Average SSQ total score associated with the deformation

3.2 Psychological Response

With respect to the skin conductance response, the integrated value of viewing videos from the measured waveform was calculated. The integrated values were standardized for each participant to avoid individual differences. A total of 22 skin conductance responses were obtained from the participants, and from this 21 skin conductance responses that could be analyzed and did not have any missing values were used.

The standardized integrated values were analyzed by a two-way factorial analysis of variance. The findings indicated an interaction between the warp and deformation, F (8,300) = 2.0193, $p < 0.05$. A test of simple main effects was performed given that a significant interaction was found.

Firstly, a test of the simple main effect of the deformation condition in each of the warp conditions indicated that the deformation effect was significant under the condition of small warp, F (4,300) = 3.6250, $p < 0.01$. The uniform thickness condition was significantly different from that of the other three deformations. Figure 5 shows the standardized average integrated value of skin conductance for each deformation.

Next, a test of simple main effect of the deformation condition in each of the deformation condition indicated that the warp effect was significant under the condition of uniform thickness, F (2,300) = 4.6639, p < 0.05. There was a significant difference between the no warp and small warp conditions. Figure 6 shows the standardized average integrated value of skin conductance for each warp.

The skin conductance response was an indicator of "the sweat gland activity controlled by the sympathetic nerve" [6]. Previous research suggested that "the sympathetic nervous system works for the first time when a subject is under stress such as being nervous or excited" [7]. Therefore, it appeared that the conditions under which standardized average integrated value was positive were likely to cause motion sickness.

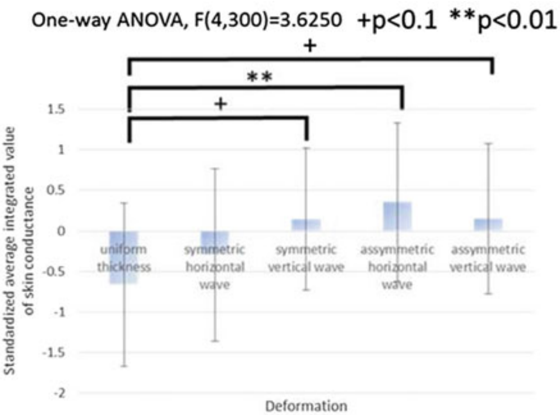
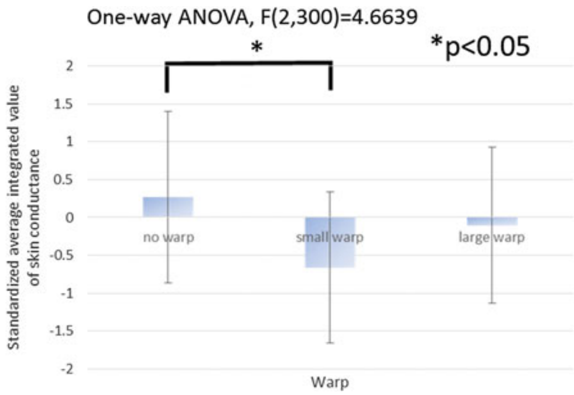


Fig. 5 Standardized average integrated value of skin conductance associated with the different types of deformations

Fig. 6 Standardized average integrated value of skin conductance associated with the different type of warp conditions

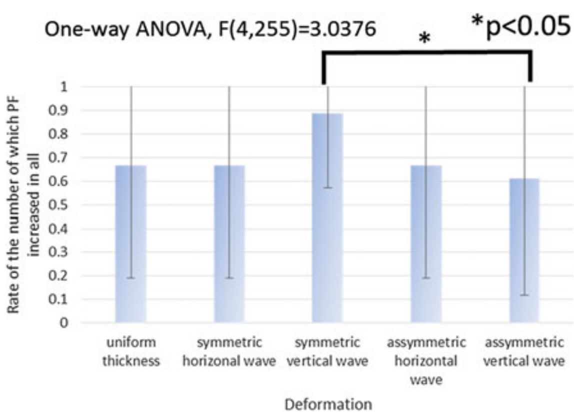


With respect to respiratory rates and patterns, the peak frequency (PF) was calculated in the resting and viewing videos from the measured waveform by fast Fourier transform (FFT). Then, we calculated a variable that indicated the increase in the PF. This variable was 1 when the PF increased within the viewing video, and it was 0 if the PF did not increase within the viewing video. A total of 22 skin conductance responses were obtained from the participants, and 18 of them that were analyzable or did not have missing values were used.

The variable was analyzed by a two-way factorial analysis of variance. The findings indicated that the deformation effect was significant, $F(4,315) = 9.7676$, $p < 0.05$, and that there was no interaction between the warp and deformation. A significant difference between asymmetric vertical wave and symmetric vertical wave was revealed. Figure 7 shows the rate of the number of PF-type increased in all for each deformation.

The increase in the PF is an indicator of light motion sickness [8]. Therefore, viewing from the window of non-uniform thickness (symmetric vertical wave) is more likely than other deformations to cause motion sickness.

Fig. 7 Rate of the number of which PF-type increased in all associated with warp



With respect to the other psychological responses (heart rate (photoplethysmogram levels), continuous blood pressure values, and electrogastrogram measurements), the warp and the deformation effect were not significant, and there was no interaction between warp and deformation.

4 Result

4.1 *Influence on Motion Sickness by the Window of Warp and Deformation*

The results in the previous section revealed that there certain conditions under which the standardized average integrated value was positive were likely to cause motion sickness in some indicators. This section focused on these conditions, and discussed the influences on motion sickness by the window of warp and deformation from the results in the previous section.

Firstly, from the subjective evaluation (SSQ) result, the window of non-uniform thickness (symmetric vertical wave) was significantly different from that of other deformations. Additionally, the asymmetric vertical wave score was larger than the scores of other deformations except for symmetric vertical wave. Therefore, the vertical wave was more likely than the horizontal wave to cause motion sickness. In other words, it was suggested that the vertical deformation influenced the motion sickness.

According to existing studies [9], [10], in the field of ship, the vertical vibration of 0.2–0.33 Hz is considered as the frequency that causes motion sickness most easily. Furthermore, an experiment involving a rabbit that was given linear acceleration in the up and down/forward and backward/left and right directions was also conducted [11]. The results of the electrogastrogram measurement suggested that the forward and backward movement most strongly inhibited gastric peristalsis, followed by the left and right, and then the up and down movements. Therefore, it could be likely that more time is involved to relieve discomfort when individuals experience stomach discomfort from a vertical motion such as those in the experiment in this study. These points suggested the relevance of the up and down motion and motion sickness.

Conversely, the average total score was not high. It was implies that a respondent was in motion sickness if SSQ total score exceeded 100. In the experiment, only the score of one participant score sometimes exceeded 100. Therefore, motion sickness caused by the experiment was light. The psychological responses were also known as the indicators of motion sickness. However, there were no interactions and main effects on any conditions due to the mild symptoms.

Secondly, the skin conductance results indicated that there was an interaction between warp and deformation. Given the small warp condition, the conditions under which standardized average integrated value was positive included the following: non-uniform thickness: symmetric vertical wave, asymmetric horizontal wave, and asymmetric vertical wave. Therefore, the influence of these deformations on motion sickness exceeded that of the no deformation under this condition. On the other hand, the standardized average integrated value was positive under the no warp condition in the uniform thickness condition. Therefore, the influence by the no warp was larger than other warps under the condition. That is, if a window has no deformation, then bending the glass decreased the influence.

Third, from the PF result, viewing from the window of non-uniform thickness (symmetric vertical wave) was likely to cause the increase in the PF. The increase in the PF was an indicator of light motion sickness, and implied the activation of the sympathetic nervous system by the fast respiratory rhythm. Thus, the motion sickness symptoms appeared in the form of an increase in PF. Additionally, the symmetric vertical wave scored the highest in all the conditions. This result was similar to the SSQ results. Therefore, the results of subjective evaluation (SSQ) were also supported by the psychological response (the increase of PF).

4.2 *Requirements of Window Shape from the Viewpoint of Motion Sickness*

The fore-mentioned discussion in 4-1 allows the consideration window shape requirements from the motion sickness viewpoint. The deformation (variation in thickness of glass) included a significant difference in SSQ and the increase of the PF. A significant differences was noted at some points when this was compared to the total number of points measured by the approach.

However, even if the motion sickness caused by the experiment was very mild, certain points involved significant differences, and the deformation (variation in thickness of glass) was considered to be highly involved with respect to window shape requirements.

For example, the result of the SSQ analysis revealed that the windows with blurring on both sides or in the vertical direction caused more motion sickness.

Conversely, for the warp, there was no significant difference in all indicators except for skin conductance response. Hence, the warp was not very involved in causing motion sickness.

Furthermore, the result of interactions caused by skin conductance suggested that “If warp of window is small, then the influence from the window thickness variability is greater” and “If there was no deformation in the window, windows with little warp will cause less motion sickness.”

These observations resulted in the following requirements for window shape:

- The variation in the glass thickness of glass should not be in the vertical direction.
- The variation in the glass thickness should not be on both sides of a window.
- With respect to the warp

A window does not have a small warp if the window has glass thickness variations.

A window has some warp if a window has no glass thickness variations.

5 Conclusion

This study experimentally investigated the influences of the window of warp and deformation change in the response to multiple combinations of conditions on motion sickness. The results indicated significant differences with respect to three points: subjective evaluation, skin conductance response, and the PF. These results suggested the following requirements for window shape:

- The variation in the glass thickness of glass should not be in the vertical direction.
- The variation in the glass thickness should not be on both sides of a window.
- With respect to the warp

A window does not have a small warp if the window has glass thickness variations.

A window has some warp if a window has no glass thickness variations.

The results of this study could be adopted for car body designs in the future. For example, large warps or deformations in horizontal direction window can be selected for cars used by a family. Additionally, for the other elements of cars like vehicle height or width that are limited by window shapes, various ideas are possible given that the requirements causing motion sickness were obtained. According to the car body shape standards (the safety standards for road trucking vehicles), there are standards for the durability or visibility of the window glass. However, there are no standards for the window shape or size, except that the window cannot jut out from car body. This suggests that as long as the windows meet the standard of durability and visibility, new window shapes such as deformation in the horizontal direction or windows jutting out from car body can be used for car body design.

However, the approach specified in this study requires further development. First, motion sickness is caused by both the information from eyesight, and by the contradiction between the information from eyesight and the vestibular information (for example the swing of the car) could also cause motion sickness. Hence, future research should consider whether the results will be the same when changes occur in vestibular information (for example a swinging car body). Also, other sickness-inducing visual elements like flowing landscape speed or view angles should be considered to derive more accurate requirements of car window shapes from the viewpoint of motion sickness.

References

1. Kimura, T.: Car design in the last ten years. J. Soc. Automot. Eng. Jpn. **64**, 85–89 (2010)
2. Reason, J.T., Brand J.J.: Motion Sickness. Academic Press, London (1975)
3. ISO IWA3:2005.: Image safety—reducing the incidence of undesirable biomedical effects caused by visual image sequences (2005)
4. Ujike, H.: Developing an evaluation system of visually induced motion sickness for safe usage of moving images: fermentation of a social understanding to supply secure and comfortable images through integration of researches on human characteristics, image analysis technique and image production technique. Synthesiology **3**, 180–189 (2010)
5. Kennedy, R.S., Lane, N.E., Berbaum, K.S., Lilienthal, M.G.: A simulator sickness questionnaire (SSQ): a new method for quantifying simulator sickness. Int. J. Aviat. Psychol. **3**, 203–220 (1993)
6. Ogata, M., Inoshita, H., Ninomiya, T.: Psychophysiological study of autogenic training. Research Report by Special Expense for Educational Research in the 1991 Academic Year, pp. 625–632 (1992)
7. Yukari, M., Mitsuo, I., Toshio, S., Taku, M., Shin-ichi, K.: Evaluation of the effect on physiological indicators of River Landscape. Environ. Sci. **24**, 218–224 (2011)
8. Nakagawa, C.: A study on the evaluation of motion sickness by using physiological responses (in Japanese), Doctoral Dissertation, University of Keio, pp. 119–121 (2007)
9. O'Hanlon, J.F., McCauley, M.E.: Motion Sickness incidence as a function of the frequency and acceleration of vertical sinusoidal motion. Aerosp. Med. **45**, 366–369 (1974)
10. Potvin, A.R., Sadoff, M., Billingham, J.: Motion sickness and otolith sensitivity: a pilot study of habituation to linear acceleration. Aviat. Space Environ. Med. **48**, 1068–1075 (1977)
11. Matsunaga, T., Uetsuka, H., Tamaki, H., Furukawa, Y., Miyoshi, T.: Changes in gastric EMG resulting from difference in direction of linear acceleration in rabbits. ORL J. Oto-Rhino-Laryngol. Relat. Spec. **40**, 101–110 (1978)

Impact of an Augmented Reality System on Learning for Army Military Decision-Making Process (MDMP) Course

Chia-Chi Mao, Chien-Hsu Chen and Chung-Chong Sun

Abstract Augmented Reality (AR) as a technology with great potential has recognized to impact affective and cognitive learning outcomes in the field of educational research. In the present study indicate, that the proposed education method based on AR technology can improve learning motivation and attention. A better interactive learning environment was established by this AR method. The research used AR technology and mobile devices such as cell phone in the teaching environment of mission analysis package of MDMP as the target. An experimental group and a control group were designed to evaluate the communication between teacher and students, including the advantages of learning cognition. Divided into two groups (classes), 40 officers receiving the training in Army Command and Staff College were the subjects of this research. The results showed that the proposed method could strengthen the communication conditions between the teacher and learners, and improve the students' cognition and understand of the operating procedure.

Keywords Augmented reality · Mobile · MDMP · Visualization · Cognitive load

C.-C. Mao (✉) · C.-H. Chen
Department of Industrial Design, National Cheng-Kung University,
No. 1, Daxue Road East District, Tainan, Taiwan (ROC)
e-mail: ideamou@gmail.com

C.-H. Chen
e-mail: chenhsu@mail.ncku.edu.tw

C.-C. Sun
The Army Command and Staff College, ROC National Defense University,
No. 1000, XingFeng Road District, Taoyuan, Taiwan (ROC)
e-mail: Jack0921982569@yahoo.com.tw

M. Soares et al. (eds.), *Advances in Ergonomics Modeling, Usability & Special Populations*, Advances in Intelligent Systems and Computing 486,
DOI 10.1007/978-3-319-41685-4_58

1 Introduction

Army Military Decision-Making Process (MDMP) refers to the Army Command and Staff College conducts education of the Advance Course in Taiwan. To nurture the command and staff officers, MDMP is used to train the officers' abilities, such as command and staff operating procedure, war analysis, and operations planning. From 2004, the Army of Taiwan implemented the MDMP of the US Army in army command and staff operating procedure. Taiwan has been developing MDMP for almost a decade. However, problems were found in MDMP application including teaching, military exercise, and guideline revision. As a result, the Army Command and Staff College needs a breakthrough in the current MDMP teaching.

Based on the FM 5-0 operation guidelines of the United States Armed Forces, the current MDMP in Taiwan was divided into two stages, including (1) Receipt of Mission, (2) Mission Analysis, (3) Course of action (COA) Development, (4) COA Analysis, (5) COA Comparison, (6) COA Approval, and (7) Orders Production [1]. The situation in the battlefield is ever-changing, and military operations involves diverse aspects. However, the preparation of MDMP teaching often requires great amount of time in the related information collection. According to the learning experience of the researcher and the interview with MDMP students, the preparation of MDMP course is highly complex. Adhering to the teaching materials and guidelines leads to the limitation in learning motivation and critical thinking ability.

According to, the Army's model for the exercise of C2 is the operations process. The operations process consists of the major C2 activities performed during operations: planning, preparing, executing, and continuously assessing the operation. The commander drives the operations process through battle command is shown in Fig. 1. We found the execution of C2 (command and control) can be presented in the visualized format of the best solution. Because as commanders begin to understand the situation and the problem, they often start envisioning potential solutions. Collectively, this is known as the commander's visualization—the mental process of developing situational understanding, determining a desired end state, and envisioning a broad concept on how the force may achieve the end state. The commander's visualization provides the basis for developing plans and orders. During execution, it helps commanders determine if, when, and what to decide as they adapt to changing conditions [2].

Research on the combination of AR/VR digital technology and mobile devices has been conducted in military and various educational disciplines. For instance, the operation training of the United States Armed Forces already adopted information technology (computer simulation system) as the tool facilitating teaching. According to the future plan, information technology is integrated with the development of various operational laboratories. Since 1980, the Defense Advanced Research Projects Agency, DARPA, has studied the utilization of multimedia technology combined with the military discipline. In the meantime, the United States Military Academy started to apply modern "digitalized instruction"

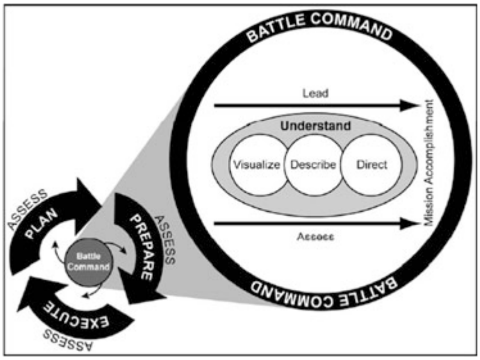


Fig. 1 Battle command and the operations process [2]

method, such as computer, television, broadcast, and communications satellite, to teaching.

Besides, four military services laboratory tests for their respective troops battle plan were systematically established in the Army, Navy, Air Force, United States Marine Corps. A number of joint operations to large scale synthesis laboratory training or exercises for the armed services were established afterwards.

Most of mobile learning studies emphasize the adoption of digital learning aids in real-life scenarios [3], the interaction between digital learning aids and the actual environment needs to be emphasized to enable students to effectively manage and incorporate personal knowledge [4]. For example, it is expiated that students can select a virtual learning object from the actual environment using a mobile learning aid, which allows them to obtain a first-hand understanding of the learning environment and, subsequently, increases their learning motivations and experiences. Such a learning support technology is achievable through the use of Augmented Reality (AR), which combines human senses (e.g., sight, sound, and touch) with virtual objects to facilitate real-world environment interactions for users to achieve an authentic perception of the environment [5].

On the other hand, when adopting the means of digitalized tool and AR in the learning context, the cognitive load of the students should also be considered. Human beings can understand though cognitive system, if the analysis of a large amount of information passed to visualization, will be able to provide a more intuitive thought ability. As Hutchins [6] in terms of military staff work, is clearly to be more efficient, more direct cognitive tools, and visualization can improve the brain's ability to analyze large amounts of data, and enables better interaction between computer and human channels [6]. Improving cognitive systems often means tightening the loop between a person, computer-based tools, and other individuals. On the one hand, we have the human visual system, a flexible pattern finder, coupled with an adaptive decision-making mechanism. On the other hand are the computational power and vast information resources of the computer and the World Wide Web. Interactive visualizations are increasingly the interface between the two. Improving these interfaces can substantially improve the performance of the entire system [7].

The preliminary evaluation method adopted in this research selected the AR integrated with the “Mission analysis presentation” in the mission analysis stage as the scope. “Mission analysis presentation” used various transparency map and figures to report to the commander. The content of the presentation includes the conditions of the war zone, the influence of weather, and the combination, capability, intention, possible operations of the enemy. The explored issue was whether the visualized information presented through mobile device with AR and 3D animation technique improved the student’s understanding of MDMP course and judgement of operation information, including the student’s learning motivation and effect.

This research explored the application of AR in the “mission analysis” stage of MDMP. The goal of this research includes:

Improving the learning motivation and effect of MDMP education

Decrease the cognitive load in the MDMP learning process

Promote the integration of AR technology and the development of military education training.

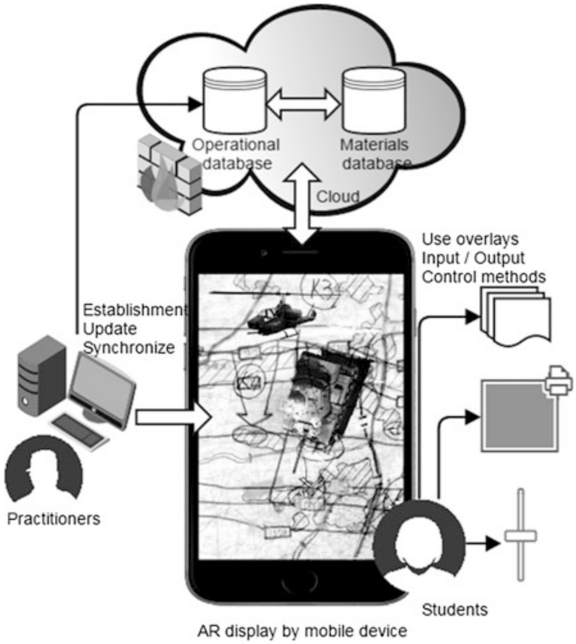
2 Augmented Reality-Based Mobile Learning Approach

The greatest advantage of combining mobile devices with MDMP education is transferring original paper-based information into digitalized information. Besides, extra information including graphics, video clips, and 3D animation is presented in the original map to provide virtual scenarios. From the literature that learning scenario can be real or virtual. Learners can learn in the scenario generated by the multimedia of the computer. Besides, through the simulation graphics produced by AR, an interactive virtual scenario can be provided [8].

Visual effects can be utilized to show the combination of abstract and real conditions. Visual effects provide students with the opportunity of operation real-time information access. Therefore, the thinking and decision-making ability of students are improved. The simulations is a design duplicating the actual condition or phenomenon. The design helps the learners to make decisions based on logical thinking, observation, and understanding of the reality [8].

The presentation of sensory characteristics is only achievable through the level of environmental reality and activity immersion; therefore, different levels of sensory experience can be achieved through different display and positioning technologies. Furthermore, if the augmented information of the real object is comprehensive, the sensory experience and knowledge transmission will be accurate; conversely, if the augmented information is incomplete, the sensory input and knowledge transfer will be inaccurate [4]. Considering these points, We reconstruct a AR learning system to change the current teaching methods, and to increase learning motivation and Benefits by enhancing the students’ sensory experience, see Fig. 2.

Fig. 2 System structure of the interactive AR-based mobile learning



The AR-based mobile learning system was developed for Unity software and iphone6 plus, combined with the original military map used in teaching. The major function of AR system is to improve education methods and the education effect of MDMP, therefore the traditional educational procedure is still remained. In order to maintain flexibility on teaching and students' adaptable, as Figs. 3 and 4 shows the traditional teaching mode and the structure of the new system, which teacher, students, big map, operation overlays, mobile devices and notebook.

Fig. 3 Traditional teaching mode of MDMP

Fig. 4 Base on AR system teaching mode of MDMP

3 Experiment Design

Participants

The participants of this experiment were students with at least 10 years of experiences in the army troops from the Army Command and Staff College in Northern Taiwan. A total of 40 students were included in this study, ranging between 32 and 45 years of age. These students were from two classes (experimental and control group); and the two group with the same materials and the relevant conditions in the classroom, as well as the same instructor was responsible for both classes.

Experimental Procedure

Figure 5 shows the experimental procedure. During the learning activity, the content of MDMP course confirmed that the students had an equivalent basic prior knowledge of the natural science course content. The students in both groups were trained to operate the mobile learning devices before the 120-min inquiry-based investigation. During the learning activity, the students in the experimental group learned with the AR-based mobile learning approach. On the other hand, those in the control group used traditional learning approach; Afterwards, the same mission analysis presentation was conducted.

Measuring Tools

This paper adopted the Questionnaire for User Interaction Satisfaction (QUIS), a tool developed by a multi-disciplinary team of researchers in the Human/Computer Interaction Lab (HCIL) at UMCP [9]. The QUIS was designed to evaluate user's subjective satisfaction with specific aspects of the human/computer interface [9]. A total of 10 questions in five dimensions were employed and assessed using a seven-point Likert scale anchored by "strongly disagree" (1) to "strongly agree" (7); that is, the influence of the visualized information (Visualization), the capability of providing more information in time (information), the assistance in students'

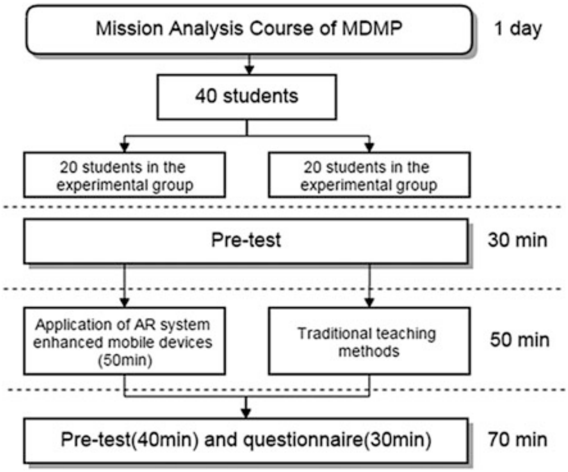


Fig. 5 The experimental procedure

decision-making (Assistance), and the students need to feel satisfied after completing the learning activities (Satisfaction).

The cognitive load survey developed by Sweller et al. [10] was used to measure the cognitive load of individual students [10]. The main purpose of the questionnaire was to assess whether using a tablet computer as a learning tool generates cognitive load. The questionnaire covers 4 questions; one measure the students' mental load using a seven-point scale.

4 Results

Evaluation on Learning Effect

Before the experiment, the two groups took a pre-test to ensure that they had equal abilities in this subject before the learning activity. The means and standard deviations of the pre-test were 3.60 and 1.13 for the experimental group, and 3.80 and 1.15 for the control group. The t-test result showed that these two groups did not differ significantly ($t = 1.95$, $p > 0.05$); that is, the two groups of students had statistically equivalent abilities before learning the subject unit.

After participating in the learning activity, the two groups of students took a post-test. The t-test result shows that the average learning evaluation of the experimental group was significantly better than that of the control group ($t = -3.942$ $p < 0.001$), as shown in Table 1. From the above results, it is concluded that the mobile AR approach is helpful to the students in improving learning for Army of MDMP and can also provide other functions such as more detailed battle data, information synchrony, and teamwork assistance giving.

Table 1 t-test results of learning evaluation of the two groups

Variables	Group	N	M	SD	t
Visualization effect	Experimental group	40	5.35	1.08	−6.27***
	Control group	40	3.60	1.13	
Information	Experimental group	40	4.10	1.17	−2.91**
	Control group	40	3.40	0.93	
Assistance	Experimental group	40	4.50	0.99	−3.82***
	Control group	40	3.65	1.12	
Collaborative	Experimental group	40	4.63	1.10	−2.76**
	Control group	40	3.88	1.20	
Satisfaction	Experimental group	40	4.00	0.99	−3.95***
	Control group	40	3.03	1.05	

**$p < 0.01$
***$p < 0.001$

Table 2 t-test results of the cognitive load of the two groups

Variables	Group	N	M	SD	t
Mental load	Experimental group	40	4.94	1.07	−5.27***
	Control group	40	3.24	1.01	

***$p < 0.001$

Cognitive load

The aim of using the cognitive load measure was to evaluate whether the students' performances were affected accept and use the new tool rapidly, and the learning strategies adopted. The experimental results showed that the means and SD values were 2.02 and 0.83 for the experimental group, and 2.27 and 0.79 for the control group. Moreover, the t-test results for the cognitive loads of the two groups were $t = -1.168$ and $p > 0.05$, indicating that the two groups' cognitive loads did not differ significantly.

Table 2 shows the experimental group's mean = 4.94 and SD = 1.07, while the control group's mean = 3.24 and SD = 1.01. The t-test analysis results showed that $t = -5.27$, $p > 0.001$, indicating that no significant difference was found. From the means of the two groups, it was found that students will not cause more mental load, but is helpful for learning to understand for AR mobile learning approach.

5 Discussion and Conclusions

Based on the results of the current study, we can draw the following five conclusions: (a) The mobile AR approach is able to improve students' learning performance in learning motivation and efficiency. (b) Students can adapt the integration of AR mobile learning approach. (c) Utilizing digital teaching methods can improve the efficiency of information searching and filing. (d) Utilizing the teaching simulation conducted by AR mobile learning approach can inspire students' judgment, creativity, and enhance team cooperation. (e) AR systematic teaching mod-el can efficiently enhance MDMP educational training.

There are two advantages of the system conducted in this study: first, utilizing open software and the current mobile device could be implemented without in-creasing budget, which would be economic benefit to army educational unit. Second, AR system integrates current teaching methods and not changing the design of the course, therefore, it would not change the teaching and acquiring purpose. In addition, AR system has great possibilities of expansion and operation to Command and Staff course. Not only apply to MDMP, it can integrate with terrain exercise to make images, texts, videos, and 3D animation through AR system to show the function of virtual-reality interaction and information updating and synchrony. Thus, it would great improve the effectiveness of education.

The further research will focus on how much information AR system display, how the army map integrate with reality map, and UI design application. In addition to, in the near future, we will try to apply this approach to other mobile learning applications, including terrain exercise and war game e.g. overall, we believe that this study is an important step to improve the army education and training in our country.

References

1. Sun, C.: The thinking systems to enhancement and promote for Army Military decision-making process (MDMP). WHAMPOA Interdiscip. J. **66**, 89–108 (2014)
2. George, W., Casey, J.: Fm 5-0: the operations process (2010)
3. Sharples, M., Arnedillo-Sánchez, I., Milrad, M., Vavoula, G.: Mobile learning: small devices, big issues. In: Technology-enhanced learning: principles and products, pp. 233–249. Springer Netherlands (2009)
4. Wu, H.K., Lee, S.W.Y., Chang, H.Y., Liang, J.C.: Current status, opportunities and challenges of augmented reality in education. Comput. Educ. **62**, 41–49 (2013)
5. Azuma, R., Azuma, R.: A survey of augmented reality. Presence Teleop. Virtual Environ. **6**, 355–385 (1997)
6. Hutchins, E.: Cognition in the wild (1995). http://hci.ucsd.edu/hutchins/citw.html
7. Keim, D.A.: Information visualization and visual data mining. IEEE Trans. Vis. Comput. Graph. **8**, 1–8 (2002)
8. Zhi-Hao, F.: A study of military education and training on virtual reality technology—the U.S. Army as an example (2010)
9. Harper, B.D., Norman, K.L.: Improving user satisfaction: the questionnaire for user interaction satisfaction version 5.5. Proc. Mid Atl. Hum. Factors Conf. 224–228 (1998)
10. Sweller, J., van Merrienboer, J.J.G., Paas, F.G.W.C.: Cognitive architecture and instructional design. Educ. Psychol. Rev. **10**, 251–296 (1998)