Lecture Notes in Networks and Systems 259

Hasan Ayaz
Umer Asgher
Lucas Paletta *Editors*

Advances in Neuroergonomics and Cognitive Engineering

Proceedings of the AHFE 2021 Virtual Conferences on Neuroergonomics and Cognitive Engineering, Industrial Cognitive Ergonomics and Engineering Psychology, and Cognitive Computing and Internet of Things, July 25–29, 2021, USA

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12th International Conference on Applied Human Factors and Ergonomics and the Affiliated Conferences (AHFE 2021)

Proceedings of the AHFE 2021 Virtual Conferences on Neuroergonomics and Cognitive Engineering, Industrial Cognitive Ergonomics and Engineering Psychology, and Cognitive Computing and Internet of Things, July 25–29, 2021, USA.

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Preface

This book brings together a set of contributed articles on emerging practices and future trends in cognitive engineering and neuroergonomics both aiming at harmoniously integrating human operator and computational system, the former through a tighter cognitive fit and the latter through a more effective neural fit with the system in solving complex problems at the intersection of human and technology. The chapters in this book uncover novel discoveries and communicate new understanding and the most recent advances in the areas of cognitive neuroscience, mental workload and stress, human error and risk, mental state and systemic-structural activity theory. Further topics include neuroergonomic measures, neuroinformatics, cognitive computing and associated applications.

The book is organized into 12 sections:

Neuroergonomics and Cognitive Engineering

1. Modeling and Monitoring Humans for Operational Task Performance
2. Real-World Human State Assessment: Victories and Remaining Challenges
3. Cognitive State Assessment
4. Neurobusiness Applications
5. Systemic-Structural Activity Theory

Industrial Cognitive Ergonomics

6. Brain–Machine Interface (BMI) and Neuroinformatics
7. Human–Machine interaction and Learning Systems
8. Cognitive Neuroscience, Health Care and Artificial Intelligence (AI) Systems

Cognitive Computing and Internet of Things (IoT)

9. Cognitive Living Spaces Using IoT Devices
10. Intelligent Computing and Cognitive Computing in Health Care

11. Cognitive Assessment and Physical Strain of First Responders and Action Forces
12. Multimodal Measurements, Artificial Intelligence and Mental Structure

Sections 1 to 5 include contributions to the International Conference on Neuroergonomics and Cognitive Engineering. Sections 6 to 8 include contributions to the International Conference on Industrial Cognitive Ergonomics and Engineering Psychology (ICEEP), and Sections 9 to 12 include contributions to the International Conference on Cognitive Computing and Internet of Things (IoT). The three conferences examine the cognitive ergonomic aspects of a workplace to understand a working task and solve a problem, thus making human–system interaction compatible with human cognitive abilities and limitations at work. It discusses optimal human-work parameters, such as mental workload, decision making, skilled performance, human reliability, human–system design, human–computer interaction, work stress and training, as these may relate to worker's ability to properly construe the task, in order to avoid hazard, errors, misperception, frustration and mental work overload.

Collectively, the chapters in this book have the goal of offering a deeper understanding of the couplings between external behavioral and internal mental actions, which can be used to design harmonious work and play environments that seamlessly integrate human, technical and social systems.

Each chapter of this book was either reviewed or contributed by members of the Scientific Advisory Board. For this, our sincere thanks and appreciation go to the Board members listed below:

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We hope that this book will offer an informative and valuable resource to professionals, researchers and students alike, and that it helps them understand innovative concepts, theories and applications in the areas of cognitive engineering and neuroergonomics. Beyond basic understanding, the contributions are meant to inspire critical thinking for future research that further establish the fledgling field of neuroergonomics and sharpen the more seasoned practice of cognitive engineering. While we do not know where the confluence of these two fields will lead, they will certainly transform the very nature of human–system interaction, resulting in a yet-to-be-envisioned design that improves form, function, efficiency and the overall user experience for all.

This book is dedicated to Gregory Bedny for his pioneering work in the systemic-structural activity theory and for the outstanding scientific contribution to the field of neuroergonomics.

July 2021

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Umer Asgher
Lucas Paletta

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Neurobusiness Applications

Systemic-Structural Activity Theory

Brain-Machine Interface (BMI) and Neuroinformatics

Modeling and Monitoring Humans for Operational Task Performance

Planned Investigations to Address Acute Central Nervous System Effects of Space Radiation Exposure with Human Performance Data

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Abstract. This work intends to generate evidence of acute, incremental human performance decrement similar to that due to space radiation and its impacts on the brain, to accompany ongoing human performance modeling work. The planned work will explore the boundaries of human behavioral and performance decrement after exposure to stress, which may be expected based in part on rodent responses found after exposure to ionizing radiation. The collection of evidence via simulation studies can characterize real human errors toward determining what stress levels lead to significantly-low levels of performance (below permissible outcome limits) which would imperil mission accomplishment. If mission-relevant animal-study-linked tasks are used, human and animal performance levels may be aligned to enable quantitative assignment of permissible exposure limits based on animal exposure studies. Ultimately, a transfer function between the performances of exposed rodents and humans under stress can be developed using shared impairment mechanisms.

Keywords: Human performance · Space radiation · Operational task performance · Stress · Cognition

1 Introduction

Acute stressors threaten operational mission accomplishment by hindering human performance. Performance degradation may be modeled and predicted, or measured in real time to mitigate risks to task and mission completion during operations. Ideally, human performance data collected during simulated or real task performance is used to verify models and fit parameters. When used together, stress detection, psychophysiological monitoring, cognitive evaluation and performance measurement, simulation scenario design, and physiological response and cognitive impact modeling can be powerful tools for mitigating the risks of degraded operational task performance.

To accompany ongoing work modeling human performance decrement due to the multiple stressors of space exploration [1], human performance data collection during simulated task completion is being planned. This work intends to generate and gather evidence of acute, incremental human performance decrement similar to that due to

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functional impairment caused by space radiation (SR), and in particular due to the impacts of SR on the central nervous system including the brain. The planned work intends to explore the boundaries of human behavioral and performance decrement after exposure to stress, which will vary across mission durations and functional domains. These studies will be guided by performance decrement expectations based in part on rodent responses found after exposure to ionizing radiation [2]. Despite such literature, questions remain regarding how to set appropriate human exposure limits in a way that is based quantifiably on expected human performance and associated mission outcomes. Additional human performance data - whether newly-generated or obtained via analysis of existing data sets - is needed to transfer outcome limits to exposure limits. This will be further addressed in Sect. 2.

Some level of human error is tolerable while still achieving mission objectives, regardless of whether those errors can be measured with statistical significance. Levels of human error which imperil a mission are not tolerable. These would be significantly-low levels of performance (SLP). Thus, we plan the collection of evidence to characterize real human errors on either side of these limits toward answering the following questions.

1. What stress level (or simulated radiation exposure level) leads to a SLP, across task difficulty levels and functional task types? This must be determined so that data may be collected for both simulated mission failure and accomplishment.
2. Given an acute impairment of <*functional ability*>, human performance decrement may be expected on tasks which rely on <*functional ability*>. What is the impact to the mission if the <*functional ability*>-requiring tasks are not performed well? At what point does that impact become significant to mission accomplishment?

Relevant experimental design considerations are discussed in Sect. 3. Ultimately, a transfer function between the performances of exposed rodents and humans under stress can be developed using shared impairment mechanisms [3, 4] and SLP alignment based on this newly-gathered evidence that addresses operational significance.

2 Transferring Human Performance Outcome Limits to Animal Exposure Levels

Radiation exposure is limited via mission planning to protect crew health and mission accomplishment. Given appropriate human subject data, permissible exposure limits (PEL) may be set in a way that is based quantifiably on expected human performance and associated mission outcomes. The collection of evidence via human subject simulation studies can support the characterization of real human errors toward determining what stress levels lead to SLP on operational tasks which would imperil mission accomplishment. Such low levels of performance would lead to undesirable mission outcomes - those below permissible outcome limits (POL).

As illustrated in Fig. 1, mission-relevant POLs cannot be set effectively using animal studies alone. It is unreasonable to expect rodents to perform complex multi-function tasks at the mission level in a way that approaches human performance. However, if mission-relevant yet *animal-study-linked* tasks are used, human and animal performance levels may be aligned to enable quantitative assignment of PELs based on animal exposure studies, using POLs based on human SLP studies. Task selection is discussed further in Sect. 3.

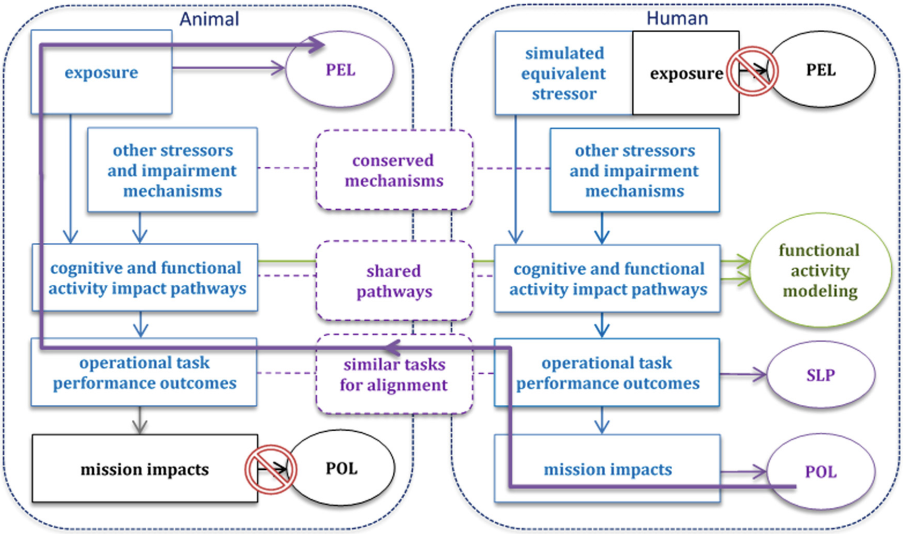

Fig. 1. Steps from exposure to mission impacts are shown, for animals (*left*) and for humans (*right*). Given appropriate human subject data, permissible exposure limits (PEL) may be set in a way that is based quantifiably on expected human performance and associated mission outcomes. Determination of the significantly-low level of performance (SLP) enables mission-relevant permissible outcome limits (POL) to be transferred through aligned analogous task performance outcomes to animal exposure limits (*via the path depicted from POL to PEL*).

Further, human PELs cannot be set directly via human exposure studies for ethical reasons. However, *in-task* human performance outcomes that align - as practically as possible - with animal performance outcomes would enable the tracing of human outcome limits to animal exposure limits, and the establishment of POL-based PELs via the path depicted from POL to PEL in Fig. 1. Determination of the SLP threshold allows these limits to be set according to mission impact thresholds. The SLP determines the minimum level of animal performance in response to radiation insult that corresponds to analogous human performance which supports mission success. The dose at that response level points to the animal and the analogous human PEL.

Conserved stressors and impairment mechanisms, and shared functional pathways, provide additional touchpoints to underpin a quantitative connection to the animal data for human-animal translation. Functional activity modeling enables the tracing of insult to certain brain regions or networks through cognitive performance and finally to behavioral outcomes. It also supports the mapping of rodent to human brain functional impairment findings for documentation, communication, and understanding of the shared cognitive processes which underlie impairment effects and behavioral outcomes across species for future explorations and translation efforts.

This approach is limited by the complexity of dose response curves used to characterize operational task performance outcomes. Lacking a mechanistic understanding that could provide information from theoretical considerations and having limited empirical data, the overall shape of the dose response for performance decrements is largely unknown. This can provide particular difficulty in estimating thresholds or more generally the response in any portion of the curve where it may be rapidly changing. This situation can be difficult to resolve empirically because measuring the response at many doses would be required, and this is typically limited by the practical cost considerations of running the required studies. Simply fitting the data to a single model can often give misleading results because the resulting predictions can be heavily dependent on subjective model choice. This dependency is typically not included in the statistical uncertainty estimates, ultimately giving a false sense of accuracy. This type of problem is typically dealt with by using some form of model ensemble where multiple models are considered and used to estimate uncertainties that include the form of the model as well as different measures of central tendency. Examples of this type of approach that have been developed specifically to handle the case of possible effect thresholds include models to estimate the cardiovascular disease risk from radiation exposure [5] as well as methods to estimate thresholds for regulatory applications in toxicology [6]. Ensemble models are also being considered more generally to estimate space radiation risks [7].

Further, when considering animal dose response curves that are flat with a low exposure threshold for performance impact, a PEL is not practical and the performance decrement due to that exposure may be unavoidable. To protect human performance outcomes and enable mission accomplishment, compensatory mechanisms such as cognitive reserve may be relied upon, autonomous job aids may be added, or task load and other stressors may be reduced such that POLs may be met or exceeded. In these cases, the understanding of the relevant POL afforded by well-defined SLPs becomes even more important to overall mission planning and the mitigation of overall integrated risk, since staying below the PEL is not an option.

3 Experimental Design Considerations

A potential human subject study approach to the collection of the needed human subject data includes the induction of stress responses via: impairment mechanisms shared across species (e.g., social stress, toxicity, or brain network interference), physiological symptom induction (e.g., weakness), or other sources of impairments (e.g., ethanol or sleep deprivation) [3]. Future studies might involve disruption of the default mode network in both species [8, 9] as it is relevant to human performance [10] and measurable in an ambulatory fashion [11, 12]. The purpose of the stress induction is to simulate the performance decrement that may be expected with radiation exposure that is otherwise unethical to perform on human subjects.

An example general test plan is provided in Table 1. Tasks and missions increase in difficulty and workload from I to IV. Note that task performance will induce stress as well, which we separate from *non-task-induced* stress. Simulated exposure levels for stress induction begin at I with no exposure. Levels of *non-task-induced* stress due to simulated exposure increase from II to IV. Data are collected for each case, or trial scenario.

Table 1. An example general test plan for measuring performance decrement and mission outcomes to enable the identification of SLP. Tasks and missions increase in difficulty, workload, and stress from I to IV. Simulated exposure levels begin at I with no exposure. Levels of *non-task-induced* stress due to simulated exposure increase from II to IV.

	Simulated exposure I	Simulated exposure II	Simulated exposure III	Simulated exposure IV
Tasks and mission I	Scenario 1A	Scenario 1B	Scenario 1C	Scenario 1D
Tasks and mission II	Scenario 2A	Scenario 2B	Scenario 2C	Scenario 2D
Tasks and mission III	Scenario 3A	Scenario 3B	Scenario 3C	Scenario 3D
Tasks and mission IV	Scenario 4A	Scenario 4B	Scenario 4C	Scenario 4D

Participant groups may be: control participants (with no "exposure") performing tasks and accomplishing a simulated mission, "exposed" participants performing the same tasks and missions under varying levels of stress, control participants performing more difficult tasks and missions, and "exposed" participants performing more difficult tasks and missions. These methods enable determination of the combined mission difficulty and induced stress levels which lead to simulated mission failure, thus identifying the SLP for various scenarios.

3.1 Task and Mission Selection

For this work, missions performed during simulation trials are made up of multiple subtasks collected together and adapted to simulate the achievement of an overall objective for each trial scenario. The tasks selected must be multi-functional to cover multiple cognitive domains. Note that these tasks are not operational performance *readiness* measures such as the Psychomotor Vigilance Test [10], but should address similar domains. They also must be mission-relevant and well informed by ongoing programmatic work and SME-based publications describing skills and knowledge important and relevant to design reference missions (e.g., Stuster et al. 2018) [13]. Further, they must be analogous to those used in relevant animal exposure studies (see Kiffer et al. 2019 for a recent review) [2] to provide grounds for the SLP-to-response alignment discussed in Sect. 2. Additionally, some of the sub-tasks must be implementable with variable difficulty to allow for mission difficulty calibration with initial trials as discussed in Sect. 3.2.

For one mission example, a high workload human landing system simulation may be used, with an overall mission objective of landing on the lunar surface. Sub-tasks could be included to require sensorimotor skill application for lander operation, vigilance and attention for landing configuration selection and off-nominal hazard awareness, and memory for landing site recognition. For each domain, a task that is analogous to an established animal task would be adapted such that its performance is necessary for mission success for the trial. Manual control inputs could be measured to track handling during descent. Attentional set shifting [2, 14] could be implemented by changing cues to a preferred vehicle configuration depending on the current terrain to address vigilance and attention, or to exercise new rule acquisition to solve emergent problems. The Novel Object Recognition task could serve as the analogous animal task for the memory domain [15, 16].

3.2 Determining Significantly-Low Levels of Performance

Mission outcomes may be recorded as success or failure, such as achieving (or not) a damage-free landing in the proper configuration at the correct site on the lunar surface for the example of Sect. 3.1. Once mission outcomes are determined, the measured performance levels on each of the sub-tasks that led to those not achieved may be identified as the SLP for that task. This is the alignment that enables the transfer form POL to PEL as described in Sect. 2, or informs the selection and implementation of alternate, non-PEL-based mitigation methods.

Pilot trials will be needed to identify outcome range endpoints, to calibrate difficulty levels, and to determine gradual increases in simulated "exposure" stress. Conceptually, scenario 1D should be easily doable while scenario 4D should be nearly impossible to accomplish. Initial study results may indicate which level of mission difficulty and which level of simulated "exposure" stress combine to provide the required performance data on either side of the SLP. Thus, once sufficient difficulty and stress levels have been determined, future trials may not require the full experimental design to produce per-task SLP metrics useful for alignment and translation.

Whether each SLP should be identified on a per-person basis will have implications for how such studies are run. Individualized SLP determination is inline with small astronaut population pools in which individual variability is significant. If they are identified on a per-person basis, then each participant will be required to perform all scenarios in the test plan. This points to a possible need for different scenarios 1A, 1B, 1C, 1D due to potential practice effects. However, generalized SLP determination is likely a more realistic goal. With a large enough group of participants, four different groups could be used while re-using the scenarios across them, obviating scenario versions A, B, C, and D.

3.3 Measures and Evaluation

Cognitive evaluation and performance data may be collected using physiological sensing including functional neuroimaging, and behavioural performance metrics. The purposes of physiological measures are to verify stress induction, and possibly to detect high workload, executive attention, or perseveration [17, 18]. Behavioural performance metrics for each of the mission-related sub-tasks, and overall mission success metrics, are key to SLP determination. Finally, cognitive task battery performance would be useful for baseline measures as warranted for the mission sub-tasks selected.

4 Conclusions

The currently planned work can serve to develop viable human subject study methods to: 1) generate evidence to support the validation of human performance models, 2) assist with bridging the gap of translation of performance variability evidence from rodents to humans, and 3) in general promote the collection of data on real human errors to complement modeling work with data-driven methods. This can be achieved by beginning with one quadrant of the example test plan overview in Table 1. Any transfer function determined would be evolving based on additional studies and dose response characterization, dependent upon the cognitive tasks used, and guided by functional activity modeling.

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Investigating the Modulation of Spatio-Temporal and Oscillatory Power Dynamics by Perceptible and Non-perceptible Rhythmic Light Stimulation

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Abstract. Several studies emphasize the great potential of rhythmic light stimulation to evoke steady-state visual evoked potentials (SSVEPs) measured via electroencephalographic (EEG) recordings as a safe method to modulate brain activity. In the current study, we investigated visual event-related potentials (ERPs) and oscillatory power evoked by perceptible (above a previously estimated individual threshold) and non-perceptible (below the individual threshold) frequency-modulated rhythmic light stimulation at 10 Hz via a light-emitting diode. Furthermore, we examined the effect of overt and covert attention by asking participants to (1) directly focus on the light source (overt attention condition) and (2) indirectly attend it (covert attention condition). Our results revealed entrainment effects reflected in both ERPs and oscillatory power in the EEG even for a stimulation intensity below the individual perceptibility threshold and without directly fixating the light source. This non-invasive stimulation method shows strong potential for naturalistic non-clinical applications.

Keywords: Neuroergonomics · Electroencephalography · Oscillatory power · Event-related potentials · Non-perceptible and perceptible stimulation · Attention · Steady-state visual evoked potentials

1 Introduction

In the last decades, the phenomenon of synchronized neuronal firing, so-called steady-state visual evoked potentials (SSVEPs; e.g., [1]), evoked by rhythmic light stimulation

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has been intensively researched. SSVEPs are neurophysiological responses that can be measured via the electroencephalography (EEG) and are well suited for brain computer interface (BCI) applications due to their high signal-to-noise ratio (SNR) [2, 3]. Moreover, such rhythmic light stimulations are suggested to be a safe method to modulate brain activity and seem to have effects comparable to other non-invasive brain stimulation [4, 5]. Especially, frequency-modulated (FM) stimulations are promising protocols allowing for less perceptible visual stimulation and, thus, decrease of potential eye fatigue and user discomfort [6–8]. During a FM stimulation, the carrier frequency (usually a high frequency, e.g., 40 Hz) is modulated by a second frequency (i.e., the modulation frequency, e.g., 30 Hz) and SSVEPs are evoked at the frequency of the difference (40–30 = 10 Hz). Some studies indicate that strongest EEG power modulations are elicited when the stimulation source is positioned in the center of the visual field and directly fixated [1, 9]. However, it is of particular importance for real-world applications to explore protocols characterized by (1) high user comfort (e.g., by using less perceptible rhythmic stimulation) and (2) feasibility; especially when aiming to integrate the stimulation in everyday life environments (e.g., in a car interior [3]) as well as their respective processes of action (e.g., by using a protocol which does not require direct fixation on the light source, c.f., [7, 8]). Therefore, we investigated topographical modulations (time domain) by measuring ERPs and modulations of oscillatory power (frequency domain) for the four rhythmic light conditions: (1) perceptible FM stimulation with amplitudes of the flickering intensity above a previously estimated individual threshold and (2) non-perceptible FM stimulation with amplitudes below the individual threshold with either (a) direct fixation on the stimulation source (overt attention) or (b) fixation on a crosshair presented 10 cm below the light source (covert attention) in each stimulation condition.

2 Methods

2.1 Participants

EEG data from 12 participants from the same dataset used in [8] were reanalyzed (ten men, mean age of 26.83, $SD = 3.80$). Participants were screened to have normal or corrected-to-normal vision and a visual acuity above 0.7[1]. Furthermore, they were excluded when reporting neurological deficits, central effective medication, drug consumption, or psychiatric disorders. Participants were informed about risk of epileptic seizure due to the rhythmic visual stimulation and signed an informed consent according to recommendations of the declaration of Helsinki. The study was approved by the ethics committee of the Medical Faculty, University of Tuebingen, Germany.

2.2 Apparatus and Stimuli

As in [8], a white-colored light-emitting diode (LED; 2800 K with a peak at 600 nm, diameter 0.5 cm, Model NSPL500DS, Nichia Corporation) with a homogeneous diffusor covering 1.14° of the visual field was mounted in front of a black screen with 1 m distance to the nasion. A crosshair was positioned 10 cm below the LED as fixation point in the

[1] It was measured via the Freiburg Visual Acuity Test [10].

covert condition covering 5.7° of the visual field. The LED was driven by a close-to-real-time capable industrial PC (10 μs; 16-bit). The stimulation and EEG recordings were synchronized via a parallel port and CANopen interface. The rhythmic stimulation was generated with a Beckhoff Framework programmed by AIOCAS S.a.r.l. using a FM stimulation protocol adapted from [6, 7]:

$$signal = A + FV * sin(2 * \pi * Fc * t + (M * sin(2 * \pi * Fm * t))). \quad (1)$$

A represents the amplitude of the current intensity and was estimated individually to define the perceptibility threshold (IPT). *FV* is the fluctuation of the current intensity span with 0.2 mA, *Fc* the carrier frequency (40 Hz), *Fm* the corresponding modulation frequency (30 Hz), *M* the modulation index ($M = 2$) (2), *t* the time vector. Hence, to entrain brain activity, the LED was driven by FM signals at 10 Hz calculated by the difference of *Fc* and *Fm* (40 Hz–30 Hz)[2].

EEG Data Acquisition. EEG potentials were recorded according to the international 10–20 system from the following 32 positions[3] (actiCAP and BrainAmp, BrainProducts GmbH, Germany). The EEG was grounded to FCz and the left mastoid was used as common reference. The impedance was kept below 20 kΩ at the onset of the experiment. The data was digitized at 1000 Hz, high-pass filtered with a time constant of 10 s, and saved for off-line analysis via the BrainVision Recorder (BrainProducts GmbH, Germany).

2.3 Procedure

Participants were seated in a mock-up vehicle interior in a dark recording chamber. First, a 3 min EEG resting state baseline (eyes open and fixated on a crosshair under a shallowly illuminated static light condition; $M = 20$ cd/m^2) was recorded (cf. [8]).

To investigate perceptibility, we designed stimuli either perceptibly flickering above the individual perceptibility threshold intensity (i.e., IPT + 2 mA; A-IPT) or non-perceptibly below the threshold (i.e., IPT - 2 mA; B-IPT). The threshold intensity was estimated prior to the main session with the method of constant stimuli [11] separately for the overt and covert attention condition using 10 repetitions of 14 stimuli (total of 280) with 10 flickering[4] and four static control stimuli without flickering[5]. To cue the attention-based condition, either an arrow signalizing the participant to focus on the LED (overt condition) or a crosshair (covert condition) was presented 8 s before the stimulation onset. In this pre-session, the stimulus was presented for a maximum of 8 s up to 30 s and participants were asked to decide whether the stimulus was flickering or

[2] Since we used a LED with a linear current-to-luminosity curve for the current range used in the experiment, we prevented additional harmonics in the signal due to the fact that the sinusoidal current variations translate into a non-sinusoidal (distorted) light intensity variation.

[3] Positions: Fp1, Fp2, AFz, F7, F3, Fz, F4, F8, FT9, FC5, FC1, FC2, FC6, FT10, C3, Cz, C4, T7, T8, CP5, CP1, CP2, CP6, TP10, P7, P3, Pz, P4, P8, O1, Oz, O2

[4] Flickering stimuli: 0.5 mA, 1 mA, 2 mA, 3 mA, 4 mA, 5 mA, 6 mA, 7 mA, 8 mA, 9 mA

[5] Static control stimuli: 1 mA, 3 mA, 5 mA, 7 mA

not by button press as soon as possible and within 30 s of the stimulation. Each trial was followed by an inter-stimulus interval (ISI) of 10 s.

In the main session, 252 stimuli were presented in 2 (attention; overt - covert) × 3 (perceptibility; A-IPT – B-IPT – static) conditions with 42 repetitions per condition. The conditions were presented block-wise with seven randomized conditions as trials within each block (ISI of 30 s) and six repetitions of the condition within each trial (ISI of 8 s). The attention-based condition was cued 2 s (either with the crosshair or arrow) followed by an 8 s stimulation interval. We Latin-square counterbalanced the order of the conditions within a block with the constraint that the attention-based conditions are (1) alternated and b) equally balanced and pseudo-randomized among participants regarding their order and starting condition. In total, each run lasted 108 s with a break of 30 s afterwards. Each block was followed by a 2 min break. Figure 1 provides an overview of the procedure of the main session.

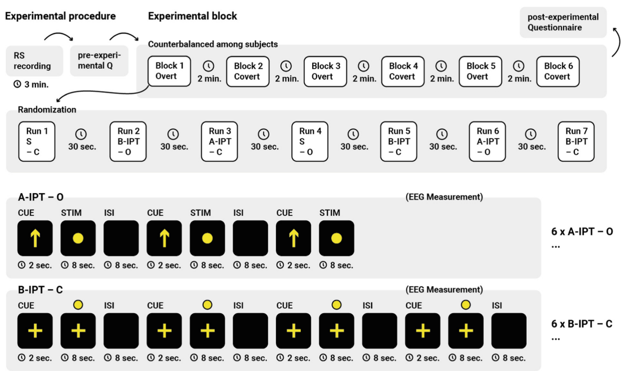

Fig. 1. Experimental procedure of the main session. *RS*: resting state, *Q*: questionnaire; *STIM*: stimulation; *CUE:* cue before the stimulation signaling the attention-based condition; *ISI*: inter-stimulus interval, *S*: static condition, *A-IPT*: above the individual threshold condition, *B-IPT*: below the individual threshold condition; *C*: covert; *O*: overt.

2.4 Data Analysis

EEG Pre-processing. EEG signals were de-trended, zero-padded, and re-referenced to mathematically linked mastoids [12]. We excluded five EEG channels (FT9, FT10, T7, T8, and CP1) from analysis due to artifact contamination. All EEG signals were filtered with a first order zero-phase lag finite impulse response (FIR) filter using a narrow frequency band of 0.5 to 22 Hz for the ERPs and a band-pass filter between 0.5 to 40 Hz for the oscillatory power analysis. The continuous EEG signals were segmented separately for the four conditions with a time window of (1) [−200 to 600 ms] for the ERPs, and 2) [2000 to 6000 ms] for the oscillatory power analysis. Segments containing a maximum deviation above 200 µV in any of the frontal EEG channels (Fp1, Fp2) were rejected. We performed an independent component analysis (ICA) using the logistic infomax algorithm [13] to remove further ocular movement, cardiac, and muscular artifacts via visual inspection of the topography, time course, and power spectral intensity of the components [14, 15]. Furthermore, the resting state EEG data later used for normalization from each participant was pre-processed as described above for the oscillatory power analysis and divided into non-overlapping epochs of 2 s.

ERP Analysis. For the ERP analysis in the time domain, EEG segments were baseline corrected by subtracting the mean amplitude of a 200 ms time interval before stimulation onset. Signals were then averaged over trials, occipital electrodes (O1, O2), and participants to calculate the grand averages of the ERPs for each condition (see Fig. 2A). To study the topographical changes of the ERPs, three components were statistically evaluated based on [16] (see Fig. 2B and 2C): the (1) P90 [75 to 145 ms], (2) N180 [170 to 245 ms], and (3) P300 [280 to 400 ms]. We used a cluster-based non-parametric randomization approach with multiple comparisons correction [17, 18]. A multiple dependent sample t-test on the level of individual electrodes was conducted on the ERP components of the comparisons (1) covert vs. overt condition for A-IPT and B-IPT and (2) A-IPT vs. B-IPT for covert and overt [cf., 19]. Hence, t-values exceeding the a priori threshold of $p < .05$ (uncorrected) were spatially clustered based on neighboring electrodes. The cluster level statistics were defined as the sum of t-values within each cluster. We corrected for multiple comparisons by calculating the 95th percentile (two-tailed) of the maximum values of summed t-values estimated from an empirical reference distribution. t-values exceeding this threshold were, thus, considered as significant at $p < .05$ (corrected). Reference distribution of maximum values was obtained by means of a permutation test (1000 permutations).

Oscillatory Power Analysis. For the calculation of power, we defined regions of interest (ROIs): frontal (F3, Fz, and F4), parietal (P3, Pz, and P4), and occipital electrodes (O1, Oz, and O2). We calculated the power spectra (2–35 Hz) of (1) the resting state and (2) stimulation conditions per ROI for each participant via the fast Fourier transformation (FFT). For the statistical analysis, power was transformed to a dB scale, normalized per condition with the resting state, and binned to frequency bands of interest with alpha (8 to 12 Hz) and beta (18 to 22 Hz) as the first harmonic response. We used a within-subject design with two factors perceptibility (A-IPT and B-IPT) and attention (overt and covert) with non-parametric Friedman's Q-tests to statistically analyze the oscillatory power. Subjects revealing extreme reactions to the stimulation were identified as outliers by $M + -2 * SD$ and excluded (one participant in the beta band power). Significant differences between conditions were further analyzed with non-parametric, FDR corrected post-hoc Wilcoxon signed rank tests. Data analyses were performed with custom written scripts in MATLAB® and python™.

3 Results

ERP Results. We observed strongest deflection of the components in electrodes overlying occipital regions in the overt attention condition especially during perceptible stimulation (Fig. 2 A). Comparing the spatio-temporal dynamics of the attention-based conditions (Fig. 2 B), there were reduced positive deflections in electrodes overlying parieto-occipital regions in the P90 and P300 and increased negative deflection in the N180 during the B-IPT stimulation in the covert (fixation 11.3 deg below the LED) compared to the overt condition (fixation on the LED; upper row). Interestingly, the P300 was enhanced in electrodes overlying the frontal regions in the covert condition under non-perceptible (B-IPT) stimulation. During A-IPT stimulation, reduced positive deflections in electrodes overlying parieto-occipital regions were observable only in early and late components (i.e., P90, P300; lower row). Comparing the perceptibility conditions, significant differences between perceptible (A-IPT) and non-perceptible (B-IPT) stimulations were already present in early components during covert attention (Fig. 2 C, upper row, left). The P90 and P300 were significantly reduced, whereas the N180 was enhanced in electrodes overlying fronto-central regions for the B-IPT (negativity in Fig. 2 C, upper row, due to the contrast non-perceptible vs. perceptible). Further, we found stronger negative deflections in the N180 for the perceptible (A-IPT) stimulation in electrodes overlying the parieto-occipital regions for the covert (positivity in Fig. 2 C, upper row, middle) and overt condition (Fig. 2 C, lower row, middle).

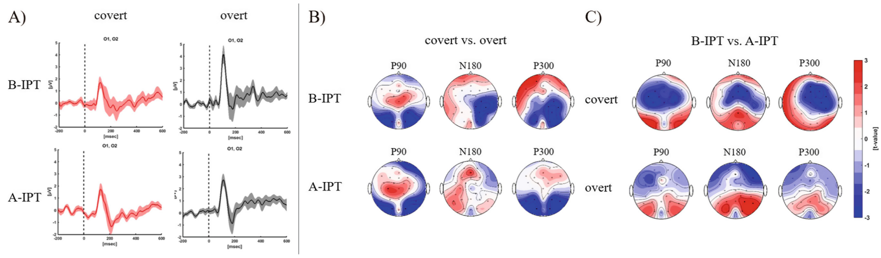

Fig. 2. A) Grand averages of the ERPs in electrodes overlying the occipital regions (O1, O2) for the four conditions. Shades represent the standard error (±SE) of the mean. B) and C) *t*-value topography differences of the P90 (left), N180 (middle), and P300 (right). Electrode clusters showing significant differences in the non-parametric randomization test are indicated by filled black circles. *B-IPT*: below the individual threshold condition; *A-IPT*: above the individual threshold condition.

Oscillatory Entrainment Results. Oscillatory entrainment in the alpha and beta band frequency did not differ between the perceptibility conditions in electrodes over occipital, frontal, and parietal regions. We observed similar power entrainment not only in the overt but also covert attention condition. There was only a significant difference in electrodes overlying occipital regions, $\chi(3) = 2.692$, $p = .021$, between the attention conditions in the non-perceptible stimulation with increased beta band power for the covert condition, $p = .014$ (FDR corrected).

4 Discussion

We observe similar oscillatory power modulations for the four stimulation protocols. In line with [9], we found increased oscillatory power in the first harmonic response (beta band power) in electrodes overlying occipital regions for the covert compared to the overt condition during non-perceptible stimulation. This finding might be especially interesting for BCI applications [20].

Regarding the ERP results, early exogenous and lately induced ERPs (likely representing the P300 complex [21]) were elicited (cf. [16, 22]). While early components (predominantly located in the primary visual cortex due to the retinotopic activation) indicate processing of psychophysical stimulus features (e.g., contrast, motion, and color [23, 24]), the later represent rather cognitive information processing.

In line with [25–27], we found a clear attention effect reflected in enlarged positive deflections when the stimulation source was overtly attended compared to the covert attention condition. This phenomenon is suggested to reflect attention-related sensory gain control mechanisms in the extrastriate visual cortex associated with enhanced SNR of visual inputs and, thus, improved acuity of visual perception within the spotlight of attention [25–27]. In addition to the reduced P300 deflection in electrodes overlying the centro-parietal/occipital cortex, we observed enhanced frontal P300 deflections for the non-perceptible unattended stimulation. It might point to attentional mechanisms and attempts to identify whether the stimulus is flickering or not. The P300 complex typically associated with the *oddball*-paradigm is sensible to infrequent, deviant stimuli indicating stimulus recognition/discrimination, task-relevant information, and selective attentional processing [21]. It is further associated with working memory capacity and updating processes [21]. Contrary to [27], the N180 deflection was enlarged in electrodes overlying parieto-occipital regions when the non-perceptible stimulation was unattended compared to the overt attention condition. The N180 complex (originally N135 but slightly shifted due to the rhythmic light stimulation [16]) activates magnocellular pathways of the visual system associated with processing of luminance, non-color, and motion related information [22–24]. A possible explanation could be cortical hyperexcitation due to reduced inhibitory activity of cortical pyramidal cells during non-perceptible and unattended stimulation [28].

5 Conclusion

Our findings indicate entrainment effects represented in both ERPs and power even for a non-perceptible stimulation and without directly fixating on the light source. This non-invasive stimulation method shows strong potential for naturalistic applications to enhance neuronal activity and cognitive processes. Especially for safety-critical situations, the possibility to enhance alertness, concentration, or/and performance is appealing. However, a complete understanding of rhythmic light stimulation is a precondition for application in traffic and other safety relevant areas. The work contributes to understanding and potential use of non-invasive and non-perceptible rhythmic light stimulation.

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Towards Artificial Social Intelligence: Inherent Features, Individual Differences, Mental Models, and Theory of Mind

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Abstract. We discuss the potential for near-future artificial social intelligences (ASIs) to exhibit functional artificial theory of mind in a video-game based teaming scenario. We also describe the impact of individual differences on mental model formation and mental state development. We focus on the possibility for an ASI to develop profiles of human agents by eliciting or observing a range of information which may influence their counterpart's behavior during a novel task. We conclude with a discussion of the implications of this approach for integrating methods from the cognitive and social sciences in development of ASI.

Keywords: Artificial intelligence · Social intelligence · Theory of mind · Mental models · Individual differences

1 Introduction

As Artificially Intelligent (AI) agents continue to progress and become more commonplace (e.g., Siri, Alexa), the need for these agents to expand beyond simple functional ability and towards team-ready, collaborative intelligence, increases [1]. To date, advances in artificial agents have primarily revolved around task related capabilities such as besting masters at strategy games and employing generative neural networks to create synthetic media. Moving beyond individual, skill-dependent, capabilities will require the integration of intelligent systems that support successful collaboration with both artificial and human agents. Studies of teams comprising only humans have shown that, to engage effectively, an individual must have the ability to determine, reflect upon, and leverage their knowledge and their teammates. Further, an individual should ideally be able to interpret the mental state of their counterparts and make predictions regarding future actions. The ability to gather such knowledge, and make accurate attributions, is a major component of social intelligence – intelligence that allows humans, and potentially artificial agents, to learn from and understand each other [2], and is foundational for interacting effectively with others to accomplish goals [3].

Winfield [2] stated that intelligent behavior can generally be defined as doing the right thing at the right time and that, in order to achieve this, an agent would need to be able to assess the context of a situation and use that information to make determinations

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of best courses-of-action. Further, an agent would likely need to be able to update and adapt its determinations based on models of itself and the world. The issue with this approach is that artificial agents solve problems in ways that are not always comprehensible to humans. For example, studies show that deep neural networks were distinguishing images based on unexpected criteria, such as the presence of snow in an image to discern between "Wolf" and "Husky" rather than truly identifying based on the object of interest [4]. Explainability of how the artificial agent arrives at its determinations helps to identify weaknesses of the AI system, verify its decisions, and foster trust.

Human-to-human interactions do not tend to suffer from lack of explainability because we have developed a reciprocal Theory of Mind (ToM) that allows us to understand ourselves as well as to predict the intents and actions of others. That ability breaks down when interacting with artificial intelligent systems because they solve problems in ways that are fundamentally different to us and have no way to explain themselves to non-expert end-users that would inform an individual's ToM of the agent [5]. Currently, artificial agents lack the capability to understand the knowledge, goals, beliefs, and emotions of other agents and to use that understanding to facilitate effective teamwork. We argue that foundational to developing this capability is artificial theory of mind (AToM) as it will underlie, inform, and shape an artificial socially intelligent (ASI) agent's interactions.

In this manuscript, we discuss the potential for ASI to exhibit functional AToM in a video-game based teaming scenario as well as the impact of individual differences on mental model formation and mental state development. Particularly, we provide a proof of concept for how an ASI can develop profiles of human agents by eliciting or observing a range of information which may influence behavior during a novel task. For future study, we additionally propose knowledge gathering functionalities which may allow ASI to generate and error correct AToM attributions as well as approaches to computationally defining an individual's ToM.

1.1 Framing the Issue: ASI and Urban Search and Rescue

The research reported here is part of a US Department of Defense program, funded through DARPA, called the *Artificial Social Intelligence for Successful Teams* (ASIST) program. The goal of ASIST is to develop the foundations of ASI capable of demonstrating the capacity to form artificial theory of mind (AToM) and the ability to support a team effectively by representing and helping to maintain shared mental models [7]. The ASIST program has opted to use Minecraft as a testbed for conducting a virtualized Urban Search and Rescue (USAR) task which serves as the basis for human-agent teaming and testing of ASI interactions. The USAR task is facilitated by a modification to the Minecraft game engine and affords human agents the ability to search for, and rescue, victims at the site of a collapsed building. The following discussion centers on insights regarding the development of human agent profiles for informing ASI team member's AToM prior to execution of the USAR task.

2 From Knowledge in the Head to Artificial Social Intelligence

2.1 Theory of Mind, Mental Models, and Human-Agent Profiles

Theory of Mind (ToM) forms one of the cornerstones of Social Intelligence. Although there have been various definitions of ToM, it is generally accepted to represent a set of cognitive skills that enable one to hypothesize about another's mental state [8]. ToM has also been described as the ability to take another's perspective [9], the ability to impute mental states to oneself and others [10], and the ability to more easily understand, predict, and influence the behavior of others [11]. Beaudoin et al. (2020) distinguished components of ToM as emotions, desires, intentions, perceptions, knowledge, beliefs, and mentalistic understanding of non-literal communication (e.g., changes in posture, sarcasm in statements). Beyond separation of components, there are distinctions between first-order ToM processes, referring to the inference of the knowledge, mental models, and mental states of another person, and second-order, which refers to the inference of someone else's ToM regarding another individual. Mental models are a particularly important element of ToM with regards to teaming as they are the cognitively-based knowledge representations we generate to produce qualitative and quantitative inferences, inform our understanding of systems, and allow us to describe, predict, and explain system behaviors [12]. In this paper, our focus is on first order ToM with emphasis on mental models (MM). An additional challenge for AToM, though, is the practical problem of measuring or capturing individual and team MM [12].

Many technological capabilities have already been developed to support the generation of MM and ToM related information (e.g., emotion classifying algorithms reliant on facial expression or information tracking tools which log agent activities and knowledge building), but we have yet to take the next step of creating socially intelligent systems for synthesizing different components into an artificial representation similar to a human's ToM. In pursuing this form of AToM functionality, we anticipate two initial challenges. The first will be identifying measurable components of Knowledge in the Head (see Fig. 1) such as the human's previous experience, mental states, emotions, etc., so as to computationally define ToM. The second will be creating embedded systems that can elicit and capture a human's ToM as well as observational information about the human's environment; those functions are necessary aspects of gathering Knowledge in the World (see Fig. 1) to make testable AToM attributions in near real time. Further, we contend that both challenges are made difficult not only by the practical work of selecting relevant constructs, appropriate methods to measure them, or approaches to AI learning, but also by the variance introduced by the variability among human team members. Individual differences in experience, personality, preferences, motivation, etc. can have significant impacts on the way that a human agent collects knowledge, develops mental models, and transitions between mental states which may shape taskwork and teamwork.

We propose that an early step towards AToM will be development of detailed (mathematical, conceptual, and/or computational) profiles of human agents which contain as much information as can be meaningfully used by an ASI. A combination of many sources and types of data may be beneficial to include in a human agent's profile. For instance, information regarding an individual's capabilities may be pertinent for an ASI

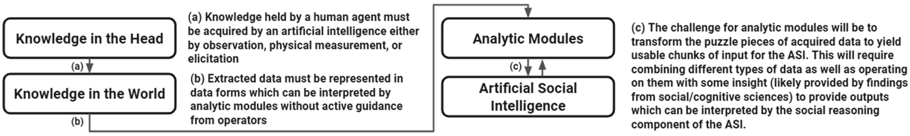


Fig. 1. High-level representation of the flow of information required for providing an artificial social intelligence with enough data to develop usable player profiles.

attempting to make predictions such as likelihood of cognitive overloading and subsequent reactions (behavioral, emotional, performance, etc.), whereas data regarding their gaming experience might inform their likelihood to undertake certain actions. In brief, these are defining mental model subcomponents of players that can help create profiles diagnostic of future player behavior. Figure 1 below illustrates a high-level depiction of checkpoints that must be passed before an ASI can make effective use of a human agent's profile data. Perhaps the most important of these stages for near-future research will be the transformation of extracted information into datasets which are embedded with sufficient information for absorption into an ASI (see Fig. 1, c). Whereas techniques for extracting Knowledge in the Head currently exist or can be readily generated (see Fig. 1, a), representing the resulting data in appropriate forms will require collaboration between multiple disciplines crossing the bridge between cognitive and social sciences and computational or artificial learning sciences.

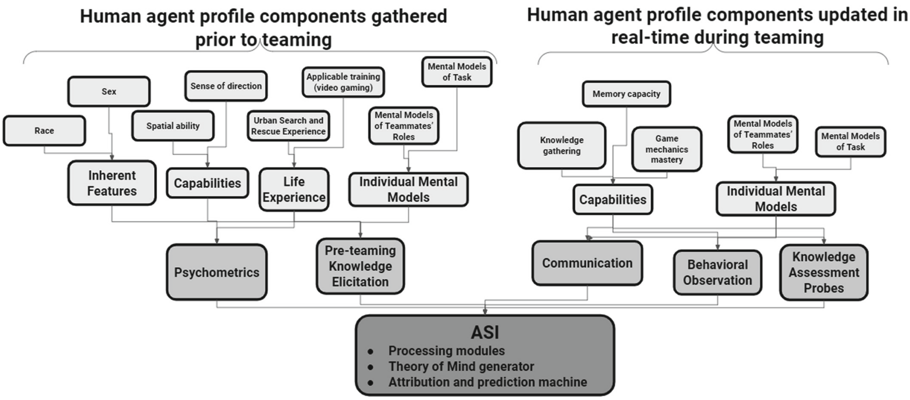


Fig. 2. A depiction of initial components potentially comprising Knowledge in the Head, and by what methods this may be gathered and processed before being entered into the workings of an ASI.

Considering the overarching goal of achieving human-ASI teaming, we note that a broad distinction in developing profiles of human agents is the time at which data may be gathered and processed. Prior to addressing the computationally difficult problem of capturing and integrating information in real time, we may first consider how to capture profile data and provide it to an ASI before any teaming occurs. The relevance of this distinction is depicted in Fig. 2 below; a great deal of data regarding inherent features and capabilities may be extracted and processed into usable forms before an ASI is involved in the equation.

We chose to approach the issue of informing AToM with the initial step of collecting knowledge representations from human agents prior to human-ASI teaming. The targets of our initial experiment were elements of an individual's experience, inherent features, and mental models. We focused this further by introducing game training to study how this altered the player mental models. Both training and prior experience should lead to some convergence of mental models. By assessing sharedness of mental models based upon sub-components described in Fig. 3, we are able to develop diagnostic profiles of human teammates. These profiles, then, can be used to examine idiosyncratic player differences. Such findings can then feed into the AToM architecture, enabling agents to more accurately observe behavior and make predictions.

3 Preliminary Data Insights

3.1 Sample and Study Design

The data represent a subset of a larger study conducted by the ASIST program. After cleaning data to remove incomplete responses and malingering participants, the original set of 200 participants was reduced to 93, grouped by whether they were trained on the details of an Urban Search and Rescue task set in a virtual environment. Due to the time required to prepare each dataset for the mental models analyses, we selected a subset of 20 participants from each group for detailed analysis. The total subset of 40 participants was predominantly male, with 22 individuals self-reporting as male and 18 as female. The overwhelming majority of participants, 38, reported their age between 18–24 years-old, with only 2 participants reporting between 24–30 years old. Additionally, our sample featured mostly self-reported White/Caucasian and Latino/Hispanic-American individuals with 22 and 13 respectively, the remainder of the sample included 4 reporting as Black/African American, and 1 indicating a category of Other.

Participants were separated into two groups: one received training on the ASIST Minecraft USAR task, the other group did not. Both groups completed surveys which captured demographics, video game experience, and Minecraft experience as well as two measures capturing mental models: a card sort (see Fig. 3) and series of paired comparisons based on constructs related to the Minecraft USAR task.

3.2 Processing Knowledge from the Head

Making use of knowledge elicited from human agents requires some level of interpretation based on either assumptions or information from previously analyzed data, such as using a known population to inform relative parameters for classifying attributes or traits (e.g., "low" or "high" spatial ability). As a proof of concept, we accomplished this manually to demonstrate the data that can be either provided by, or embedded in, collection of human agent knowledge to render it usable by an ASI.

Prior Experience. We quantify experience related to the Minecraft USAR task along two dimensions. First, experience with video games and environments was captured by years spent playing video games, number of gaming sessions in a given week, and the length of those sessions. Specific experience with Minecraft gameplay was captured by years spent playing Minecraft, consistency of game play, and self-reported experience with skills related to survival, exploration and crafting. Each experience-related response provided by participants was scored with the intent of attributing greater weight to experiences which may lead to additional familiarity with and capability in performing tasks in Minecraft. Individual item scores were compiled to yield an overall Minecraft experience score.

Inherent Features. Some individual features have been shown to have influences on the conceptualization and performance of many tasks, such as sex-related differences in a simulation-based task [12]. Although it may be relatively simple to elicit information through surveys or dialogues, it will be harder to guide the ASI on the use of the knowledge for developing AToM. Here, we take initial steps towards informing this process by gathering inherent feature data, to provide context relative to experience.

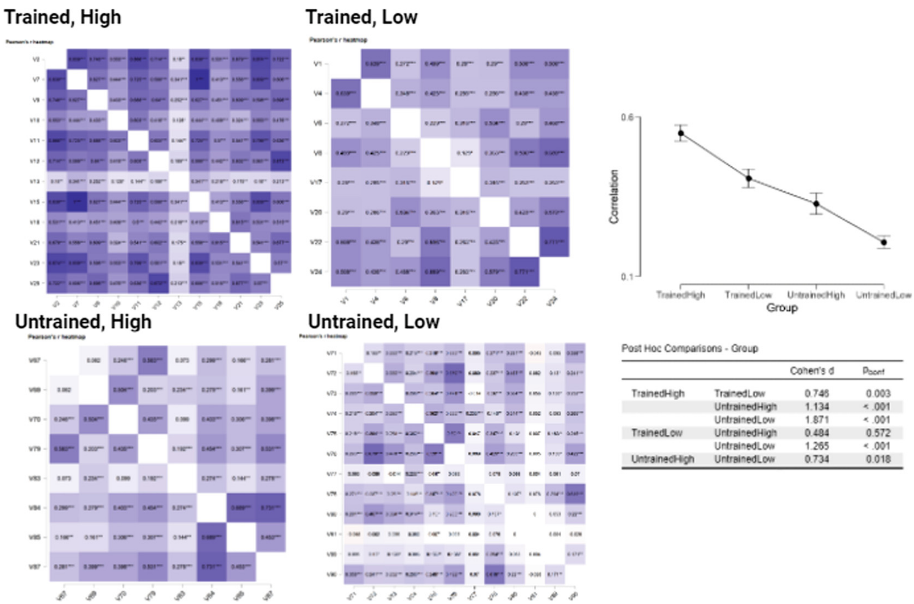
Mental Models. As mentioned, we had participants complete a card sort of concepts related to the Minecraft USAR task. Matrices of groupings were then generated to allow for correlational analysis.

3.3 Individual Differences and Minecraft USAR Mental Models

Individual Differences in Minecraft Experience. Without interpretation by a human, or guidance from a previously established dataset (or *post-hoc* distribution of scores where available), the responses provided by participants would be meaningless to an ASI. To address this, and because there was no prior reference set, we constructed questions to tap facets of experience that we hypothesized may be important (e.g., *How many years have you played Minecraft?*). From those questions, we developed a compiled metric which could be used to establish expectations of participants and make predictions. In applying this metric approach to analysis of a separate dataset, we have found that it is effective for identifying/predicting differences in participants performance of and success in the Minecraft USAR task.

Our examination of the correlations between the inherent feature variable, sex, and the aggregated Minecraft experience scores showed some sex-related differences such that males, on average, reported having more experience: Pearson's $r = -0.539$, $p < .001$. Research on video games and gaming performance often reflects these differences; however, the reason for their existence is undetermined and likely to arise from a combination of culture, societal pressures, and hobby preferences. The present sample did not show any apparent relationships between age or ethnicity and the experience variables (likely due to homogeneity); however, we contend that a generalized ASI would be best informed by gathering those factors as they have been shown to impact conceptualization of tasks as well as teaming strategies.

Individual Differences in Mental Model Formation. An individual's mental models may be influenced by many factors that will impact how they conceptualize, strategize about, and eventually behave during a task. We examined the differences in our sample's collective mental model representations by grouping them along the manipulated dimension, training (20 trained, 20 untrained), as well as by the low, high Minecraft experience metric discussed above (20 low, 20 high), resulting in the following breakdown: 12 trained high exp, 8 trained low exp, 8 untrained high exp, 12 untrained low exp. To visualize the differences in trained vs untrained and high vs low experience mental models, we generated between-participant correlations based on their groupings of constructs when completing the card sort measure (see Fig. 3).



		Cohen's d	p_{bonf}
TrainedHigh	TrainedLow	0.746	0.003
	UntrainedHigh	1.134	< .001
	UntrainedLow	1.871	< .001
TrainedLow	UntrainedHigh	0.484	0.572
	UntrainedLow	1.265	< .001
UntrainedHigh	UntrainedLow	0.734	0.018

Fig. 3. Visualization of differences in between-participant card sort correlations.

A key takeaway from the visualization in Fig. 3 is that these profile components are diagnostic of mental models and can be used to show similarities in mental models across these profile groupings. Higher correlations indicate more sharedness in mental models within profiles. Simple card sorts can capture these differences and provide important information for a potential ASI teammate. Results of a preliminary ANOVA conducted to examine differences in sharedness across profiles confirmed that those differences were measurable and significant, $F(3,184) = 41.73$, $p < .001$ (note: between-participant correlations were pooled and tagged by their respective training and experience groupings). Mental models sharedness was greatest for those who received training and had experience, but was also high based upon task related experience.

4 Concluding Remarks

The first step towards developing an Artificial Theory of Mind for inferring the mental states of human agents will be to create methods for automatically extracting, categorizing, and representing the knowledge a given agent has stored in their head. We show that some elements of an agent's knowledge set may be readily gathered prior to teaming with an Artificial Social Intelligence, and it will be on those aspects that the next steps of this research will focus. Particularly, the first step will be developing measures and automatic processing approaches which extract and prepare a human agent's knowledge in a format that can not only be processed by, but also meaningfully understood by, an ASI. Future research will extend the collection and processing of AToM related knowledge into the active teaming domain to include aspects of human-to-ASI communication as well as interpretation of behaviors and decision-making outcomes.

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Real-World Human State Assessment: Victories and Remaining Challenges

Can Situation Awareness Be Measured Physiologically?

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Abstract. To operate effectively across a variety of environments, personnel (e.g., air traffic controllers, pilots, truck drivers, emergency response crews) must develop and maintain situation awareness (SA), perceiving relevant elements in the environment, understanding their meaning, and projecting their status into the near future [1]. Although multiple SA assessment techniques have been developed, they require periodic interruptions of a task to query the individual regarding their knowledge of the situation. There has been a recent proliferation of more rugged and durable sensor devices (e.g., functional near infrared spectroscopy (fNIRS) sensors) that can be used while people take part in ecologically valid activities to assess changes in neurophysiology, physiology, and behavior that correlate with cognitive state (e.g., SA). In addition, recent advances in machine learning and modeling techniques can be used to interpret information about human states (e.g., SA) from noisy data acquired in such environments that previously was unusable. These advances provide opportunity to develop physiological measurement approaches that could provide a potential avenue for real time, continuous, and objective assessment of SA in many real-world settings. This class of measures could potentially provide a window into low SA states where an intervention may be necessary to ensure acceptable levels of performance. In this paper, we review potential SA metrics to assess their suitability for continuous real-world monitoring.

Keywords: Situation awareness · Physiology · Neurophysiology · Cognitive state

1 Introduction

Since its inception, situation awareness (SA) has been measured across a wide range of domains, using a wide variety of measurement approaches to evaluate new user interfaces and system capabilities, training programs, automation concepts, and to investigate the construct of SA itself as well as the processes that contribute to it. The vast majority of this research has been conducted in simulation environments or lower fidelity

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microworlds and games. There is also a need to develop SA metrics that can be applied in real-world settings that might allow for continuous SA monitoring and feedback, as well for as assessments of SA in non-experimental conditions. There has been a recent proliferation of more rugged and durable sensor devices (e.g., functional near infrared spectroscopy (fNIRS) sensors) that can be used while people take part in ecologically valid activities to assess changes in neurophysiology, physiology, and behavior that correlate with cognitive state. In addition, recent advances in machine learning and modeling techniques can be used to interpret information about human states (e.g., SA) from noisy data acquired in such environments that previously was unusable. In this paper, we review potential SA metrics to assess their suitability for continuous real-world monitoring.

2 Current SA Measures

SAGAT: The Situation Awareness Global Assessment Technique (SAGAT) is the current gold standard for objective SA measurement and has been heavily validated and used across a wide variety of tasks [1, 2]. A recent meta-analysis of 186 studies found that SAGAT is highly predictive of performance (90%) and is highly sensitive (96%) to study manipulations including display design, training, and automation concepts (Endsley, in review). Further, it was found not to be highly memory dependent or intrusive on primary task performance in all 15 studies that evaluated intrusiveness. SAGAT provides periodic rather than continuous assessments of SA using scenario freezes. While currently the most widely used and successful measure of SA, SAGAT was designed for simulation environments and microworlds. Although nine studies were found that used SAGAT in live environments (such as infantry and medical training), it is not recommended for safety critical situations (e.g. live flight or driving) unless appropriate safety workarounds are put in place. It has been successfully used to measure team SA in at least 14 studies.

SPAM: The Situation Present Assessment Method (SPAM) assesses SA using real-time questioning of participants, allowing for more frequent assessment [3]. In examining 25 studies that have used SPAM, it was found to have lower sensitivity than SAGAT (67% vs 96%), and resulted in problems with intrusiveness on primary task performance in 50% of the studies examined, despite the use of a 'ready' prompt prior to probe administration (Endsley, in review). In addition problems with speed-accuracy tradeoffs, sampling bias, and confounds with cognitive workload were found, making this approach unsuitable for SA measurement. While it potentially could be used in real-world environments, it has mostly been used in simulations and microworlds studies.

Subjective Measures: Subjective opinions on SA are easy to collect in a wide variety of settings. However, there is very poor correlation between objective and subjective measures of SA [4–6]. Subjective SA metrics have been shown to more closely correlate with subjective confidence levels. Behaviorally-based subjective rating scales such as SABARS may provide a more suitable basis for ongoing observer ratings of SA, but is manually intensive and therefore difficult to provide across multiple, distributed participants.

Communications: Finally, a number of researchers have recorded ongoing team communications and analyzed them to better understand team SA processes [7, 8]. This measure is easy to collect in team settings, but is limited in operations where such communications may not be present (e.g. solo flights or driving). While most communications analyses occur post-hoc, Bolstad, et al. [9] were able to use SAGAT data to train an algorithm to automatically score team SA based on team communication. This approach requires considerable domain specific training, but has promise as a continuous measure of SA in some environments.

3 Physiological Measures of SA

One possibility for measuring SA on a continuous basis in real world settings is to obtain physiological assessments that could be used to infer SA. While there is no direct physiological expression of SA, Wilson reviews several potential approaches for this that can be explored [10]. It may be possible to measure SA objectively and unobtrusively in real time using a single or a combination of physiological measures such as brain blood oxygenation (HbO) measured by fNIRS; EEG measures, such as Event Related Potentials (ERPs) (P300), theta band, Event Related Desynchronization (ERD); cardiac measures, such as heart rate (HR) and heart rate variability (HRV); and eye tracking measures, such as blink rate, blink duration, and gaze dwell time.

Although many neurophysiological and physiological sensors have historically been unusable in operational environments, the recent advancement of more rugged and unobtrusive versions of these sensors are making them useful in real world situations. For example, a rugged, portable, physiological, and neurophysiological monitoring device, the fNIRS Pioneer™ (shown in Fig. 1), is now commercially available, and measures neurophysiology (brain blood oxygenation (HbO) and basic physiological signals (e.g., HR, respiration). fNIRS sensors measure visible and infrared light reflectance in cortical tissue. These sensors, typically applied to the forehead, can be used to estimate HbO saturation levels in brain tissue, which relates to changes in SA [11]. The fNIRS device can be mounted inside a helmet, enabling an unobtrusive fit within standard protective gear. This design is resistant to the motion-induced signal degradation that can occur with less robust sensors, such as EEG.

Fig. 1. The fNIRS PioneerTM, provides ruggedized, fieldable assessment of operational activities

While fNIRS is commonly used to assess cognitive workload it can also potentially be used to assess SA. EEG is commonly used in SA research to date, and has been well documented as a valuable tool in the assessment of brain activity, including ERP and ERD [10, 12]. Research has also shown the utility of less intrusive sensors, including those for cardiac activity, eye blink rate, and electrodermal activity (EDA) [10] which can all be leveraged to assess SA.

4 A Multidimensional Approach

Because SA is very much a multi-dimensional construct, it will likely require a number of measurement approaches to assess it. This multi-measure approach is represented in Table 1. Although no single measure is likely to fully capture SA, it may be possible to capture a number of measures that can point to high or low SA states. First, measures of fatigue and low arousal on one end and cognitive overload on the other end can provide the outside boundaries where low SA is likely. Other measures may provide an indication of attention, information processing and engagement that may be indicative of level 1 SA (perception). And measures of expectancy can potentially be tapped to provide an indication of level 2 and 3 SA (comprehension and projection). Together such a battery may be useful in assessing SA in a wide variety of settings.

Table 1. Potential battery of physiological SA measures

Factor	Physiological measures
Fatigue, low arousal	Electroencephalography (EEG) (alpha), eye blink rate, eye blink duration, saccadic eye movements, heart rate, heart rate variability
Overload	EEG (alpha, theta), eye blink rate, fNIRS
Attention/Inattention	EEG, ERP, fNIRS, ERD
Engagement	EEG
Expectancy	EEG (P300), eye blink

Fatigue and Arousal: Fatigue and low arousal are both measureable physiological states that are likely to create low SA. These states may be likely in many situations including long haul flights, jobs that require extended periods of monitoring, long shifts, or work at hours that are not aligned with circadian rhythms. Fatigue, sleepiness and low arousal are indicated by decreases in HR, HRV, slowing of the dominant EEG frequency, slower saccadic eye movements, and an increased number of eye blinks of longer durations [10]. Poe, et al. demonstrated that EEG could be used to assess arousal levels that correlated with SA in a military aviation study [13].

Overload: On the other end of the spectrum, high levels of cognitive workload can also lead to low SA, which is a significant challenge in many domains [14]. Overload conditions are characterized by increasing levels of frontal EEG theta band activity, decreases in alpha band activity, as well as decreased eye blink rates [10]. Numerous studies have demonstrated that P300 is sensitive to workload effects [15], and Parasuraman and Caggiano demonstrated increased cerebral blood flow in the prefrontal cortex via an fMRI as a way of quantifying mental workload [16].

Higher cognitive workload is associated with increased prefrontal cortex (PFC) brain HbO, therefore a recent study tested the hypothesis that higher SA is associated with decreased PFC HbO [11]. Researchers used fNIRS during real world navigation where participants had to navigate a university campus using either Google Glass or a handheld smartphone. A secondary task was conducted concurrently to assess cognitive workload (the n-back) or SA (an environmental awareness task). For the n-back, participants were required to hold information in working memory and respond as to whether each stimulus matched the one presented prior. The environmental awareness task required participants to scan the environment for 30 s, at which time they were asked whether they had observed a particular object. Researchers found effects on HbO that were different for the SA task and the workload task. This study shows that SA can be measured by fNIRS in real world environments, and that it is possible to tease out SA from confounding factors such as cognitive workload, for which this sensor has become a reliable indicator.

Due to the ease of data collection, cardiac activity has been a staple of SA assessment for decades. In one study conducted in police recruits, HRV was positively correlated with SA in a shooting simulator task [17]. Better trained personnel who exhibited higher SA performed better, and were able to suppress their HRV during task execution [17]. Similarly, in a navigation task in a sailing simulator conducted with Navy recruits, those with higher SA showed a further reduced HRV (versus baseline) during the task than participants with low SA. High SA participants also showed a rebound of HRV during the recovery phase [18]. For both studies, SA was subjectively rated by trainees with a 25 question version of the SA Rating Scale (SARS), and by observers with a 15 question version of the SARS. These studies should be extended to compare these metrics to objective SA metrics.

Both EEG and fNIRS have traditionally been used to assess cognitive workload, which can reduce SA in overload conditions. It will also be important to determine in future research if these metrics can assess SA independently of workload, and the precise characteristics of the signals that would differentiate these two constructs in non-overload conditions.

Attention and Perception: Low arousal and overload (and the states leading up to them) provide two extremes that describe the ends of the cognitive workload continuum where SA is expected to be low. Within those boundaries, it will be necessary to use additional measures to determine whether individuals have good or poor SA. Measures of attention and inattention may first determine whether people are picking up on changes to task related stimuli (Level 1 SA) via ERP, ERD and fNIRS. Inattention may be reflective of attentional narrowing or poor interface design occluding important relevant information.

EEG and eye tracking were used in one laboratory study that used a simulated air-to-ground combat flight mission in which the amount of information available to the participant was manipulated to produce high and low SA conditions. EEG data showed higher theta and lower alpha in the low SA condition, eye blink duration decreased, and eye blink rate increased in the low SA condition (determined by subjective and performance measures [19]).

Catherwood, et al. demonstrated that certain EEG measures were sensitive to a loss of Level 1 SA [20]. Berka, et al. showed that EEG measures detected relevant scenario events, such as track identification, chat type, and track response time, that could lead to a measure of SA [21].

Task Engagement: Task engagement can also be assessed via EEG [22, 23], as this has been shown to be important for SA [24]. Low task engagement, such as produced by automation or by poor task design is a key indicator of low SA.

Comprehension and Projection: Any set of physiological measures useful for real time assessment of SA should be capable of assessing all three levels of SA. Those measures that have been applied to the measurement of Level 1 SA, detection of environmental stimuli, include ERP, ERD, heart rate, HbO, and blink rate [10]. Whether an individual is developing an accurate assessment of the situation and projecting upcoming events (Level 2 and 3 SA) is much more difficult to assess physiologically. Measures used in the assessment of Level 2 SA focus on engagement and expectancy, such as ERP and ERD, particularly the P300 component of ERP which has a long history and documented use in the assessment of expectancy. A surprising event or piece of information is indicative of inaccurate or incomplete SA. The rationale is that responses differ based upon "whether the operator had the proper situational model and was or was not expecting certain critical cues" and that "good SA means that a person showed expectancy to upcoming events" [10].

The P300 component of EEG has been shown to reveal when an individual perceives a surprising or unexpected stimuli [25]. In addition, eye blinks can become slower and shorter in anticipation of expected events [10]. While it may not be possible to always determine that an individual's SA is completely accurate, together these metrics could provide a useful set of indicators of SA problems. French, et al., for example, demonstrated EEG correlates of Level 2 SA based on SAGAT scores, including an increase in frontal lobe activity in the theta and gamma bands [26].

While it is difficult to assess in real time if a person is appropriately predicting the future state of events (Level 3 SA), the same measures of expectancy, engagement, and surprise used to assess Level 2 SA at Time 0:00 can be used at Time 1:00 to determine post-hoc whether the person was appropriately predicting future states at Time 0:00, providing a near-real-time assessment of Level 3 SA. The future assessment of a given situation (Level 3) becomes the current state (Levels 1 and 2) after a certain period of time has passed.

5 Summary

Although multiple SA assessment techniques have been developed, they require periodic interruptions of a task to query the individual regarding their knowledge of the situation. There has been a recent proliferation of more rugged and durable sensor devices (e.g., fNIRS sensors) that can be used while people take part in ecologically valid activities to assess changes in neurophysiology, physiology, and behavior that correlate with cognitive state. In addition, recent advances in machine learning and modeling techniques can be used to interpret information about human states (e.g., SA) from noisy data acquired in such environments that previously was unusable. These advances provide opportunity to develop physiological measurement approaches that could provide a potential avenue for real time, continuous, and objective assessment of SA in many real world settings.

Because SA is very much a multi-dimensional construct, it will likely require a number of measurement approaches to assess it. Although no single measure is likely to fully capture SA, it may be possible to capture a number of measures that can point to high or low SA states. A multi-measure approach will likely be necessary to tap into the wide range of cognitive constructs that affect SA. As the product of many cognitive processes (including attention, memory, information integration and interpretation), the successful, ongoing assessment and interpretation of complex environments requires a wide range of factors to be considered.

While each of the techniques reviewed provide at least partial windows to SA, a number of issues will need to be addressed to create valid physiological measures of SA. These include: 1) clearly differentiating SA from cognitive workload or other constructs, 2) understanding how current measures assess relate to each other, 3) developing practical, reliable and portable physiological monitors, and 4) validating this class of measures in complex, real-world domains. This class of measures could potentially provide a window into low SA states where an intervention may be necessary to ensure acceptable levels of performance.

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Towards a Measure of Situation Awareness for Space Mission Schedulers

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Abstract. The success of space flight missions relies on support provided to astronauts through specialist knowledge of ground-based personnel. One of the many essential tasks that ground personnel provide is the scheduling of flight crew daily activities. Future long duration exploration missions will require astronauts to assume planning and scheduling responsibilities in order to facilitate increased autonomy from ground support. Although situation awareness is critical to the scheduling task, a sufficient measure for this domain has not been developed. This paper documents the approach and process by which the authors developed a framework for measuring situation awareness in space mission schedulers and presents the measure applications' initial results.

Keywords: Human factors in spaceflight · Self scheduling · Situation awareness measurement · Human performance

1 Introduction

The success of space flight missions relies on the specialist knowledge of a large team of ground-based personnel who are responsible for essential tasks to support astronauts. One such task is scheduling daily activities for astronauts. Mission schedulers create schedules for the duration of the mission, ensuring that activities are scheduled efficiently and effectively. The scheduling role is therefore essential to mission success. As NASA moves toward long-duration exploration missions (e.g. Mars), pre-scheduling all astronaut activities by ground personnel becomes inefficient. Missions that operate further from Earth will have high communication latencies between the spacecraft and Mission Control Center. Instead of waiting for guidance from ground personnel, astronauts should be able to manage their own schedule, enabling them to use their time more efficiently and effectively. This requires astronauts to assume partial responsibilities of scheduling, allowing crew to be more autonomous from ground support [1]. Unfortunately, astronauts will not have the same specialist knowledge ground personnel have to develop effective schedules.

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Previous studies have identified situation awareness (SA) as one critical factor for developing effective schedules [2]. However, a gap exists in research related to understanding and defining SA within the scheduling context, and development of a sufficient measure for this domain. This paper documents the approach and process by which the authors developed a framework for measuring SA in space mission schedulers and presents initial results on the sensitivity of the developed SA measure to detect time to answer accurately.

2 Situation Awareness Overview

SA is typically defined as "the perception of the elements in the environment within a volume of time and space, the comprehension of their meaning, and the projection of their status in the near future" [3, p97]. Inherent in [3]'s commonly cited definition is the assumption that SA is categorized into three distinct levels: Level 1 is a situation assessment of the environment, Level 2 involves understanding of the current surroundings/situation and Level 3 includes the prediction of an upcoming situation or surroundings [4]. Many domains have utilized this definition, often tailored to the specific profession and environment under consideration [5]. However, there is a gap in the scheduling literature in both definition and measurement of SA. In order to adequately measure SA, it is first necessary to adequately define SA in relation to the scheduling role.

2.1 Understanding SA in Scheduling

Mission schedulers are responsible for creating astronauts' schedules for the duration of the mission. They need to ensure that activities are scheduled according to requirements, such as a specific time of day or priority of an activity, while preventing scheduling conflicts [6]. Significant experience is needed to create an effective and efficient schedule as ground-based personnel must be aware of elements that will affect the schedule, such as the spatial location of activities onboard the ISS and crew knowledge required for specific assignments. As such, creating a mission schedule for ISS generally takes several weeks to months.

To gain further insight into the meaning of SA specific to schedulers, interviews were conducted with seven subject matter experts who were current or recently retired space mission schedulers. Semi-structured interview questions focused on several topics, including scheduling task steps, strategies, and information required for an effective schedule. After transcription and application of thematic analysis, patterns emerged in the data that related to the three levels of SA: (i) Level 1 – 'Perception' (knowledge): of factors pertinent to the scheduling problem - e.g., activity requirements, activity priority, number of activities; (ii) Level 2 - 'Comprehension': an understanding of those constraints and what it means for the scheduler – e.g., it is most important to plan high priority activities; (iii) Level 3 - 'Prediction': How to plan to avoid inefficiencies - e.g., schedule high priority activities first. Interestingly, schedulers reported that experience was needed in order to build awareness and understanding of all the required elements to build an effective schedule (mapping to Levels 1 and 2 SA). A specific example included 'formal' and 'informal' constraints. Formal constraints were factors that were documented officially and explicitly for schedulers to follow (Table 1). Informal constraints were described as factors that were essential to an effective schedule but were not documented or trained. Instead, development of awareness for these constraints arose from experience (Table 1). Findings were not only relevant to understanding the development of SA in mission scheduling, but also highlighted the specific areas that may be objectively measured with an SA measurement technique.

Table 1. Formal and informal scheduling constraints considered by schedulers (Level 1 SA)

Formal scheduling constraints	Informal scheduling constraints
Activity priority	Spatial constraints onboard ISS
Activity duration	Spatial relationships of activity locations
Maximizing crew time	Activity knowledge
Activity constraints:	Flexibility of activity constraints
a) Time Range Constraint	Equipment needed (impacts duration)
b) Requires Constraint	Crew preferences/personality
c) Overlapping Activities	Crew qualifications
d) Overlapping Activities	Set up time (impacts duration)
	Crew comfort

2.2 Scheduling-Specific SA Measure Development

Several SA measurement methods are documented in the literature, spanning direct objective and subjective measures, and indirect or implicit measures (for a full review please see [7]). In relation to mission scheduling, the Situation Present Assessment Method (SPAM) [8] appears to offer several advantages, including that the measure can be used without creating interruptions, and results have been found to be less influenced by memory confounds [8]. However, other aspects of SPAM are not particularly suited to the specifics of the scheduling task; the scheduling activity is less dynamic than many other domains, including the air traffic control domain in which SPAM was originally developed. For the current study, elements of SPAM were utilized to develop a probe-based, direct measure of SA, specifically relevant for schedulers. Binary response options were provided. Utilizing the findings from the mission scheduler interviews, probe questions were developed to assess formal scheduling constraints. Questions focused on the current situation (Levels 1 and 2 SA; Did you leave 3 or more activities unscheduled?) as well as future prediction (Level 3 SA; If COMM was suddenly unavailable before 10:00, would any activities be in violation?). Our measure departed from SPAM in two manners: probing questions were given at the end of a scheduling problem task (to minimize interruptions) and workload measure of SPAM was not necessary. The experiment described below featured the initial testing of the measure.

3 Measure Implementation: Experimental Methodology

For the current study, two independent variables were used: Type of Constraint on Activities (see below for a full description of constraints) and Percentage of Constrained Activities (33% or 66% of activities), resulting in a 4 x 2 within-subjects design. A baseline trial was run as the first trial for all participants and contained no manipulations; a latin square determined the order for the remaining eight trials. Following each scheduling task trial (similar to [2]), participants completed three questions pertaining to SA. Participants were instructed to answer the questions as quickly and accurately as they could and were permitted to refer back to the completed schedule. Twelve participants (4 Female, 8 Male) naive to the scheduling task and scheduling platform (Playbook timeline tool) volunteered to participate in the study. Participant age ranged between 35 to 64 years, and all participants held a bachelor's degree or higher.

The web-based Playbook timeline tool functioned as the study platform (see [1, 9] for an overview). Participants were given a set of activities each designated as low, medium or high priority and asked to schedule these activities among three crew members. Participants were asked to schedule according to activity priority. Some activities included rules, known as constraints. The following constraints were included in the study:

- *Time Range Constraint (T)* limits the time of day an activity can be scheduled (e.g., Activity A must start no earlier than 0900 and end no later than 1030);
- *Requires Constraint (R)* states that the activity needs to have a particular resource available (e.g., Activity requires communication availability);
- *Claim Constraint (C)*
- describes a specific piece of equipment required for a particular activity (e.g., Activities A and B both claim a treadmill, therefore cannot be scheduled at the same time).
- *Ordering Constraint (O)* describes when an activity should be scheduled in relation to another activity (e.g., Activity A must be scheduled before Activity B);

4 Results

Descriptive statistics were calculated for the percentage of correct responses to SA questions. Overall, participants answered 71.60% of all questions correctly. Statistical analyses resulted in no significant differences between conditions. Descriptive statistics revealed a data trend suggesting that for 33% constrained activities, T33 (M = 69.44%) and R33 (M = 66.67%) were on average answered less accurately than C33 (M = 86.11%) and O33 (M = 72.22%). Percentage of responses for future-focused questions (M = 70.83%) were less accurate on average than present-focused questions (M = 74.17%), although the difference was not significant. Additional analyses examined time in seconds for accurate responses to SA questions. Where a participant did not answer any SA questions correctly for a specific condition, different sample sizes were recorded. A review of descriptive statistics identified that overall, response latencies were longer for the Claim and Ordering constraint conditions compared to Time Range and Requires Constraint condition. (Table 2).

Friedman's ANOVA confirmed that significant differences in accurate response time to SA questions existed between conditions ($\chi^2(8) = 20.68$, $p < 0.01$). Post hoc analyses revealed that accurate response times were faster in T33 ($z = -2.89$, $p < 0.05$) and R66 ($z = 2.56$, $p < 0.05$) than the C33 condition. Accurate responses were also significantly faster for T33 ($z = -3.11$, $p < 0.05$) and R66 ($z = 2.78$, $p < 0.05$) compared to O33. Finally, response times were significantly fast-er when compared to O66 for B ($z = -3.56$, $p < 0.01$), T33 ($z = -4.33$, $p = 0.001$), R33 ($z = -3.67$, $p = 0.005$), R66 ($z = -4.00$, $p < 0.005$), and D66 ($z = -2.67$, $p < 0.05$). Results suggest a significant main effect of constraint type on SA response latency, although not of percentage of constraint. A Wilcoxon signed rank analysis also revealed that accurate probe responses were significantly faster for present-focused SA probes ($M = 12.88$, $SD = 6.38$) the future-focused SA questions ($M = 20.42$, $SD = 11.73$), ($z = 2.51$, $p < 0.05$).

Table 2. Mean duration to respond accurately to SA questions (in seconds) by condition

Constraint Condition	n	Mean	SD
Baseline (B)	11	10.06	6.32
Time Range - 33% (T33)	12	9.89	6.20
Time Range - 66% (T66)	12	9.77	4.80
Requires - 33% (R33)	12	9.86	5.98
Requires - 66% (R66)	11	7.56	2.29
Claim - 33% (C33)	12	13.59	6.18
Claim - 66% (C66)	12	15.58	14.82
Ordering - 33% (O33)	12	21.59	24.63
Ordering - 66% (O66)	11	21.77	14.62

5 Discussion and Conclusions

A measure of SA was developed for space flight mission scheduling based on qualitative data from expert mission schedulers. The measure was utilized in an experimental study that replicated a scheduling task. A within-subjects design study investigated the effect of type of activity constraint and percentage of constrained activities on SA, as inferred from the measure. No significant effects were found for type of constraint, or percentage of constraints, on response accuracy. This result was unexpected as more constrained activities were predicted to increase complexity, and therefore, negatively affect response accuracy. One explanation for this finding is that as the participants could see their completed schedule, the likelihood of accurate answers was increased. In addition, the small sample size could have created a Type II error. Finally, the percentage of constraints condition may not have increased complexity enough to affect SA.

Results did reveal significant differences for latencies of accurate responses to SA questions, indicating that there was a main effect of constraint type on SA. Differences in response time could be an indicator of differing complexities of scheduling activities with specific types of constraints; for example, some constraints may be easier to understand than others. In line with expectations, significant differences in response times were found between present-focused and future-focused questions, suggesting that participants naive to scheduling did not develop Level 3 SA (prediction). This finding has important implications for facilitating the development of scheduling-based SA in astronauts as we assume limited scheduling experience prior to flight.

In relation to measure development, despite the adaptation of the SPAM methodology, the measure was successfully applied to a novel task and naive schedulers, for a task that is not dynamic. Initial results therefore seem to support the potential utility of this measure. A limitation of this study was that, for mission schedulers, informal constraints directly affect how to plan to avoid scheduling inefficiencies. The current study operationalized this for the naive participants and provided them with the strategy to schedule high priority activities first; for expert schedulers the task would be much more complex.

Future research is needed to investigate the ecological validity of the findings in relation to expert mission schedulers. For the wider domain, it is essential that future research investigate the process by which mission schedulers build SA from informal constraints and develop supportive aids to facilitate non-expert schedulers (such as astronauts) in the task.

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Monitoring Human Performance on Future Deep Space Missions

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Abstract. NASA and the commercial spacecraft community are working diligently to put the first woman on the moon in the 2024 timeframe. At the same time, NASA researchers are thinking about how to solve the even larger challenges that future deep space missions will bring – primary among them is crew autonomy. Deep space mission crews will face communication delays and blackouts, and in those situations, the crew may not have access to Mission Control Center (MCC) experts. They will be dependent on each other and the available information onboard to stay alive, healthy, and achieve the mission. The only conceivable way to meet the challenges of Earth independence is to enable the crew to monitor their own health and performance. A number of technologies are presently being explored by NASA to enable crew self-monitoring. This paper highlights select projects, and provides broader discussion about the need for advanced monitoring technologies.

Keywords: Human factors · Human-systems integration · Systems engineering · Aerospace · Autonomy · Neuroergonomics · Cognitiv erngineering · Human performance monitoring

1 Introduction

Astronauts on deep space missions will face obstacles and unknowns never before experienced. In addition to the altered gravity and hostile/closed environment of a spacecraft, deep space crews will face increased radiation, isolation, and distance from Earth. During Extravehicular Activity (EVA, or "spacewalk") operations, crew will experience increased physical and cognitive workload due to extended types, frequencies, and durations of tasks performed on exploration missions in partial gravity environments. All of these stressors will affect crew physical and mental health and performance in difficult-to-anticipate ways.

A deep space mission is expected to have relatively short periods of high cognitive demand, stress, and fatigue, as well as potentially long periods of cognitive underload during the transit, where boredom, loneliness, and depression can set in. Both ends of this spectrum are dangerous. In addition, deep space missions will have periods of

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communication delay and even communication blackouts; thus, crew may have limited to no communication with the NASA Mission Control Center (MCC).

To date, the monitoring of crew health and performance, and application of any needed countermeasures has been performed by the large body of experts at MCC in Houston, TX. On deep space missions, crew may be forced to be dependent on each other and the available information onboard their spacecraft to monitor their own health and performance. They must be made aware when their task performance drops significantly, when their cognitive workload is too high, when they have lost situation awareness, or when they are too stressed or too fatigued to perform well. They must be able to identify these risks, and then mitigate them with countermeasures available onboard.

The only conceivable way to meet the challenges of Earth independence is to enable the crew to monitor their own health and performance (preferably unobtrusively) as they perform their duties. Technologies and techniques must be developed to aid the crew in these self-monitoring tasks, and intelligent systems must be developed to process that data and recommend or apply mitigations.

A number of self-monitoring technologies are presently being explored by NASA to advance crew state determination capabilities. A few examples related to unsuited and suited operations are described below. Some of these are well developed and tested, and others are still in a proof-of-concept stage.

2 Select Human Performance Monitoring Technologies

Real-Time Physiological Workload Measurement. To address the need for monitoring cognitive workload during long-duration spaceflights, researchers in the NASA Johnson Space Center (JSC) Human Factors Engineering Laboratory (HFEL) tested a functional near-infrared spectroscopy (fNIRS) sensor that can be worn by a crewmember under a headband or hat for continuous workload assessment [1]. The *fNIRS Pioneer*™ sensor, developed by Charles River Analytics, was tested as part of a study focused on comparing different electronic procedures designs. Measures included situation awareness, using the Situation Presence Assessment Method (SPAM) [2], workload, using the Bedford Workload Scale [3], errors, and eye movement using an eye tracker. The *fNIRS Pioneer*™ device was included in the study as a way of "field testing" the continuous workload monitoring tool. Results were compared with subjective workload ratings from the Bedford Workload Scale, as well as eye tracking results. The fNIRs sensor and eye tracker indicated differences in workload, where the subjective Bedford scale did not. More testing is needed, but the *Pioneer*™ sensor showed promise in providing continuous workload measures during operational task performance.

Real-Time Physiological State Integration. A similar project in the JSC Hybrid Reality Laboratory aims to allow for real-time monitoring of a variety of crew physiological states. This is accomplished through the collection of various biometric sensor data. The data are integrated into a machine-learning algorithm that can output informative user status updates. Physiological data includes electroencephalogram (EEG), heart rate, and functional near-infrared spectroscopy (fNIRS), among others. These measures could be important indicators of workload or fatigue. Such an ability becomes increasingly important in the context of NASA's deep space missions, characterized by a decreased reliance upon MCC during time-critical tasks.

Exploration Medical Monitoring. A number of NASA projects aim to utilize wearables for unobtrusive collection of real-time physiological data as indicators of crew health. In one such project, the reliability and validity of monitoring hardware developed by the Canadian Space Agency was tested [4]. The prototype sensor called "On-Astronaut Wireless Sensor System," or OAWSS, measures astronaut vital signs, including heart rate, respiration, skin temperature, and galvanic skin response. Another project at the Ames Research Center (ARC) uses sensors to track ocular signals during complex tasks, demonstrating significant performance deficits for those with less sleep. Results highlight the importance of adequate and consistent sleep scheduling for crew [5]. If physiological signals can be accurately read across varying levels of activity over time, it would be an important step towards assessing crew health on longer duration space missions.

Team Interactions. Recent research has developed and expanded upon a team-interaction sensor device (body-worn badge) that monitors team member interactions through physiological and proximity measures as crew complete tasks. Metrics include frequency, duration, and quality of interactions, as well as physiological measures related to workload and performance, such as heart rate and galvanic skin response. Such a device enables data collection that may allow for a greater understanding of team dynamics over time [6].

Future Habitat Design. Monitoring of human health and performance can benefit in situ crew, but some forms of monitoring can also lead to valuable insights related to habitat design. The capability to visualize and characterize astronaut movement throughout the environment as they live and work in space can inform the design of future habitats. For example, amount of time spent in various spaces gives clues to the value and necessity of those areas; translation paths between areas can indicate that they may need to be located more closely in future habitats. One research team developed a wearable kinematic tracking system with passive vision and inertial sensors to collect data from participants in the JSC International Space Station (ISS) mockup while they navigated their habitat and performed daily tasks [7]. The researchers were able to demonstrate a high degree of accuracy in determining user position during tasks, which is promising for future development of habitat designs using these types of methods.

EVA Operations. During EVA operations on ISS today, numerous ground support personnel use custom console displays and software, mental calculations, face-to-face communication, and hand-written notes to monitor suit and vehicle systems in real-time, while crew engage in manual tasks. Teams of ground support personnel can address and correct challenges such as errors in procedure execution, incorrect hardware configurations, or life support systems issues, while allowing crew to focus on executing the physically and mentally demanding tasks at hand. Future EVA partial gravity, planetary missions will be even more physically and cognitively demanding, occur more frequently, and, due to decreased communication bandwidths and increased communication latencies between earth ground support and crew, will be more autonomous than ISS EVAs. As a result, system monitoring and decision making responsibilities will reallocate to crew and their inflight systems.

Joint Augmented Reality Visual Informatics System (JARVIS). A commonly held assumption is that arm-cuff displays or helmet displays should be capable of presenting all available information to crewmembers, enabling them to manage timelines and monitor all systems while completing EVA tasks. JARVIS is currently in development at JSC as a displays and controls solution for the Exploration extravehicular mobility unit (xEMU) suit that will be in use beyond the Artemis III missions. The goal of JARVIS is to augment EVA crew performance while enabling crew autonomy by providing direct access to information necessary for successfully meeting mission goals. The JARVIS project is developing displays with the knowledge that certain tasks, environments, and individual differences between crew may demand different levels of situation awareness and cognitive workload. More information made available to crew is not necessarily better, and only a subset of information, such as consumables, must always be monitored. These considerations, along with hardware and informatics systems limitations, such as small display areas, drive the type and amount of information that can be provided. One of the most difficult but critical design trades is the need/desire for information and display density.

Physical and Cognitive Exploration Simulations (PACES). The PACES project is developing a complement of tasks, procedures, information systems, and standard measures that simulates realistic physical and cognitive workload under flight-like exploration scenarios. This cataloged set of tasks can be used to understand risks associated with tasks and mission operations during repeated EVAs across multiple days. The software modules provide a standardized methodology to characterize and evaluate physiology, human performance and human factors data, and ability to define risks. Risks can then be categorized to measure and assess functional postures, frequency, and duration of repeated movements, and crew interaction with tools, vehicles, and interfaces. The data collected in PACES may ultimately be used in decision support systems and hardware such as JARVIS that crew use during EVA missions.

Spacesuit Design. Sensor technology currently in development may be incorporated into suits to measure human-suit interaction, such as forces, kinematics, and pressures. These sensors provide objective data to understand suit-to-body fit and contact [8]. The data, collected unobtrusively, may provide information to crew that real-time adjustments in suit fit, task load, or task duration are needed to prevent fatigue or injury. Sensor data can also inform future suit design to improve crew comfort and satisfaction, reduce cognitive and physical fatigue, and mitigate potential trauma or injury. Additionally, data may be used to develop training procedures to assist in improving suited crew performance.

3 Conclusions and Future Work

As astronauts move toward Earth independence, and away from the safety net of MCC monitoring their health and performance, they will have to be supported by sensing technologies to track their state, as well as intelligent systems to provide decision aiding and countermeasures. Detected decreases in performance may allow for adaptive displays that declutter or simplify content. Cognitive aids may also be employed to assist with tasks in place of a knowledgeable flight controller at MCC. Detected decreases in sociability and crew-to-crew interaction may signal mental health issues, the need for rest and restorative activities like recreation, or computer-based counseling. Health and performance data gathered during EVAs may drive crew decisions to modify the task or operation, or to terminate an EVA early. Reviewing this data post EVA can inform future decisions about EVA scheduling and the need for additional/different training among crew.

To achieve this vision, we will need sensors, displays, interfaces, and software distributed across vehicle, spacesuit, and ground control systems. In some cases, within- and between-individual differences in metabolic profiles, CO2 production, aerobic capacity, muscle strength, task performance, cognitive and physiological state, and other operationally relevant factors may also be incorporated to enable individualized countermeasures. This level of system functionality will not be feasible without significant investment in sensing technologies and intelligent decision support systems.

The experience, cognitive capacity, and judgement of multiple expert ground controllers who manage crewmember health and performance today cannot simply be replaced by provision of additional crewmember displays on future deep space missions. Research and development in the area of unobtrusive human health and performance monitoring and intelligent decision aiding is needed to meet this challenge. Empowering crewmembers and ground controllers with the information they need, when they need it, is critical to enabling the increasingly autonomous operations required by Exploration-class missions.

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What Did Our Model Just Learn? Hard Lessons in Applying Deep Learning to Human Factors Data

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Abstract. Deep learning is revolutionizing all areas of data science, including human factors research. Much of human factors data, however, have fundamental idiosyncrasies that make applying deep learning challenging. Further, the complexity of deep learning can make finding errors challenging and deducing what was actually learned by the model near impossible. This paper provides two case-studies in which our research group faced and overcame such challenges. It examines the root causes of each issue and discusses how they may lead to common challenges. We describe how we discovered problems and describe how we rectified them. It is our hope, that by sharing our experiences with likely common challenges, we can help other researchers in avoiding similar pitfalls.

Keywords: Human factors · Deep learning · Behavioral biometrics

1 Introduction

Advances in deep learning have led to the development of robust predictive models that can perform remarkable tasks [1]. These advances have been made possible by the availability of high-quality datasets and relatively low-cost, high-performance computing. The prevalence of low-powered wearable sensor platforms (e.g., smartphones, smart watches, etc.) and the ability to aggregate and share their data have made the prospect of using deep learning for human factors research more practical and appealing. However, applying deep learning to human factors problems is not always straightforward and hidden issues can significantly complicate efforts.

In human factors research, obtaining realistic data is more difficult than obtaining high-volume data. Consequently, data collected for human factors research suffer from complicating factors, including sample bias, missing or erroneous labels, unaccounted-for correlations, and unlabeled data. The complexity and size of deep learning models exacerbates these issues, as these models can present as black boxes, making it difficult to determine how the models make inferences and ascertain what they actually learn.

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In this paper, we describe the efforts of our research group and the many challenges stemming from the aforementioned issues, which we overcame in applying deep learning for human factors research while using multiple highly cited and publicly available datasets. Specifically, we document two scenarios, as case studies, in which we performed research for human activity recognition and behavioral biometric user-verification using smartphone data. For each case study, we provide motivation and rationale for dataset selection, insights into our approach, how we discovered issues, the root causes of said issues, and the steps we took to overcome them. We believe that many of the challenges we experienced are likely common pitfalls and the potential errors they can cause are easily overlooked. We hope that these case studies will serve as cautionary tales and provide insights for conducting deep learning research using human factors data more effectively.

2 Background

Deep learning [2] is a powerful technology capable of distilling robust prediction models from complex high-dimensional data. The power of deep learning comes from its ability to extract and compose hierarchical features automatically and directly from data. Often, the features discovered by deep learning models significantly outperform those manually engineered by experts over many years of painstaking research [3]. This advantage comes at the cost of complexity, which increases the data requirements dramatically and obfuscates how the models make decisions. Nevertheless, the performance benefits of deep learning models, and the relative abundance of large datasets, have made deep learning the go-to tool for many researchers.

Our research was funded to support the DARPA Warfighter Analytics using Smartphones for Health (WASH) program. The objective of WASH is to develop technologies to enable the United States military to monitor the health of U.S. military personnel continuously, noninvasively, and more accurately. More specifically, the program seeks to use data collected securely and privately from common sensors on modern smartphones to passively identify indicators, or symptoms, of Traumatic Brain Injury (TBI) and infectious disease. Under WASH, our research group had two main technical objectives for applying deep learning: context identification and user verification. To meet those objectives, we utilized three public datasets.

The first of these datasets, the UCI Heterogeneity Human Activity Recognition (HHAR) dataset [4], was developed to investigate the impact of smart-devices' sensor heterogeneities on activity recognition algorithms. The UCI HHAR dataset contains sensor data of 9 subjects performing 5 min of activities (*biking, walking, standing, sitting, walking up-stairs, walking down-stairs*), recorded on 8 different Android devices kept in a pouch on the waist and labeled in post by a researcher. This dataset is cited by 307 works[1] and has been used to train and validate models that learn on multiple data modalities, among other purposes.

The second dataset is the widely used UCSD ExtraSensory dataset [5]. This large dataset has over 300,000 min of data from 60 subjects. In contrast to the HHAR dataset,

[1] As reported by Google Scholar on January 15, 2021.

the ExtraSensory data was collected with an application installed directly on personal devices for approximately 7 days. The application did not require users to participate in specific activities or to keep the device in the same place on their person. This method of collection makes the dataset highly representative of activities, phone positions, and phone orientations that occur during normal device use. This widely cited dataset, with 105 papers mentioning or discussing it at the time of writing, is often used to train or validate a novel approach to recognition of activity, context, or phone position [6–10].

The third dataset, the UCI Smartphone-Based Recognition of Human Activities and Postural Transitions (SBRHAPT) [11], cited by 389 works at the time of writing, includes a group of 30 volunteers within an age bracket of 19–48 years performing a protocol of activities composed of six basic activities: three static postures (*standing, sitting, lying*) and three dynamic activities (*walking, walking downstairs and walking upstairs*) with a smartphone attached at the waist.

3 Case Study 1: Context Identification

In this scenario, our objective was to develop a method for performing accurate context identification of user activity from smartphone data. Activities/Contexts include common things such as walking, running, sitting, sleeping, etc. User activity monitoring is a critical component of our effort for understanding subject behavior and performing downstream tasks such as predicting and diagnosing mental and physical illness [4].

Our approach for developing a context identifier builds upon the DeepSense algorithm [12]. DeepSense is a deep neural network architecture for activity classification from smartphone inertial sensor data. It uses convolutional and recurrent neural networks to learn local, sensor-specific interactions, merge and map them to global interactions, and extract temporal relationships to model signal dynamics. We chose DeepSense as our baseline because it represents the state-of-the-art for activity recognition algorithms and achieves an impressive 94% balanced accuracy in identifying contexts on the HHAR dataset [12].

As initial validation of DeepSense for context identification, we ran experiments training and evaluating it on the SBRHAPT and ExtraSensory datasets. It is good practice to validate performance claims on multiple datasets, and SBRHAPT and ExtraSensory nicely complement each other for this purpose. SBRHAPT is a clean laboratory dataset with reliable ground-truth labels; however, because of this it is severely limited in its realism. It only represents a small subset of daily life activities and all activities are recorded with fixed phone positions and orientations. In contrast, ExtraSensory contains "real-world" activities and unrestricted phone positions and orientations, but the labels are less reliable because they are derived post-activities from user surveys. Together, SBRHAPT and ExtraSensory provide the right blend of pristine data for algorithm verification and noisy, diverse data for an assessment of DeepSense under real-world conditions.

Early in our testing of DeepSense, we were able to achieve activity classification (balanced) accuracy results of 85% using SBRHAPT across the activities: *walking, walking up stairs, walking down stairs, standing, sitting,* and *lying down.* This result is significantly worse than what was achieved using HHAR but is still a positive result and was above our performance objectives. In contrast, our DeepSense models could only achieve 55% classification accuracy on the same subset of activities using the ExtraSensory data. This dramatic disparity in classification performance was concerning and forced us to look deeper into the ExtraSensory dataset to determine the source of discrepancy.

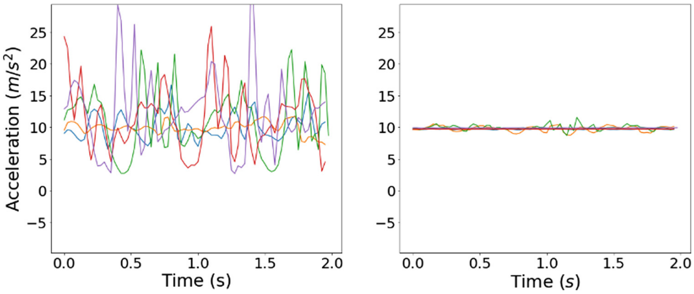

Fig. 1. Five randomly selected 2-s accelerometer sequences labeled walking that pass (left) and are rejected by (right) our energy threshold.

Aware that the activity labels of ExtraSensory data may be a source of error, we started by investigating just how unreliable the labels are. In our investigation, we discovered significant amounts of data clearly mislabeled as *walking*. Figure 1 provides illustrative examples. Both graphs show accelerometer readings for samples labeled as *walking* in the dataset. The act of walking induces a significant amount of accelerometer activity, as shown by the signals in the graph on the left, whereas the signals shown in the graph on the right lack activity and are mislabeled. To estimate the prevalence of this issue, we devised, from the HHAR dataset, a simple energy threshold test, which examined *walking* samples, evaluating whether they contained a minimum amount of energy in the signal indicative of walking. Our test found that 45% of the ExtraSensory data labeled as *walking* do not exceed the energy threshold. It should be noted that the labels were assigned to 60-s intervals, and we are using and examining subsamples at 2-s intervals. However, this lack of granularity significantly limits the utility of the supposed "ground-truth." Of the 17,525 labeled 60-s sequences of *walking* data, we found 11,065 (63%) contained at least one 2-s window that did not pass the energy threshold. Of those sequences, the average number of rejected windows was 6.6, with a standard deviation of 4.3. We also found that not all contextual labels are unreliable. For samples labeled *phone_on_table*, 97% of samples did not contain significant accelerometer energy readings, consistent with the phone being stationary.

Discovering that the ground-truth of the ExtraSensory dataset was unreliable forced us to rethink our approach. The problem renders the data unsuitable for training classifiers. Any model, deep or shallow, trained on it using the provided labels will learn incorrect decision boundaries. Nonetheless, ExtraSensory presented the most realistic data available, at the time, that more precisely and comprehensively represented our proposed use case. The clean laboratory data provided by HHAR and SBRHAPT are too limited for our purposes; we had to make use of the ExtraSensory data.

Faced with this conundrum, we realized that activity labels, or more specifically their semantic meanings, are unnecessary for our research. Our objective is to accurately monitor the activities of subjects so that deviations, indicative of illness, can be detected. Accurately identifying unique activities is critical to this task, identifying their semantic labels is not. With this insight, we pivoted towards an unsupervised learning approach that can discover structural patterns within the data consistent with distinct activities. Our approach uses a variant of Generative Adversarial Networks (GANs) [13], known as InfoGAN, which learns disentangled representations and categorizations of unlabeled data using mutual information [14]. InfoGAN provides a method for automatically categorizing, with respect to activity, the rich ExtraSensory data without dependence on activity labels. In our experimentation, we were able to verify that categories learned by InfoGAN correlated strongly with the activity labels of the HHAR dataset. Unfortunately, this approach does not provide semantically meaningful categorization or classification of the data, which could be vital to other human factors research efforts. In such cases, it may be possible to accurately infer accurate labels for specific contexts using a semi-supervised approach such as the one presented in [15]. In principle, this approach can use data with reliable labels from datasets, such as HHAR and SBRHAPT, in conjunction with unlabeled data, like ExtraSensory, to learn to separate, semantically meaningful classes.

4 Case Study 2: User Verification

One concern of our effort is that subjects, on occasion, may let others operate or handle their smartphone, leading to anomalous or irregular data that will inhibit illness detection. To mitigate this issue, we devised an approach to perform continuous user verification passively using onboard smartphone sensors. Our approach is built upon a method called Deep Vectors, or D-Vectors, which can verify subjects based on their gait cycles, observed from accelerometer and gyroscope sensors [16]. D-Vectors is a deep learning framework for automatically learning discriminative feature spaces where data from any single subject is highly localized and distant from data points of other subjects. Subjects are verified if incoming data is within a predetermined cosine distance of the subject's enrollment signature. D-Vectors has been shown to be highly effective at performing verification on multiple modalities, including mobile gait and keystrokes [16], and is ideal for performing passive authentication.

To train our verification model, we used the ExtraSensory and HHAR datasets. We chose ExtraSensory for this task, again, because of its realism. The non-laboratory conditions in which this data was collected provides a more realistic baseline of the performance of the model and the subject ID labels are reliable. However, ExtraSensory has a significant complication for this research; each subject only provides data on a single device, as such subject ID is highly correlated with the device. In contrast, the HHAR dataset contains data collected from the complete Cartesian product of 9 subjects and 6 devices, providing data that decorrelates subject identity from devices. Instead, HHAR lacks diversity in phone orientations, placements, and activities, which ExtraSensory provides.

In training and testing on both datasets, the D-Vectors model achieved Equal Error Rates (EERs) of less than .08 for data identified as *walking*. This result is consistent with the mobile-gait results reported in [16], and exceeded our requirement for the effort. However, we attempted to use D-Vectors in more activity contexts than *walking*, and the results from other contexts were surprising. Our results suggested that the D-Vector model could distinguish between subjects in the HHAR dataset based upon data labeled as *sitting*. The D-Vector approach, as implemented, is intended to use inertial sensor readings to differentiate between subjects based on how the phone moves. It should not, therefore, be able to distinguish subjects effectively during activities with no motion, such as *sitting*. That it could implied that the model was basing its decisions on a correlated feature we did not foresee. Given the complex nature of D-Vectors, and deep models in general, we were forced to examine the data and our experimental setups more carefully.

Table 1. D-Vector evaluation to determine if the sensor bias was causing the unreasonable results for user identification on other contexts using data labeled as *phone_on_table*. Lower is better.

Periodogram frequencies	Mean EER ± Std. Dev
0–20 Hz (Baseline)	0.088 ± 0.001
0.5–20 Hz	0.076 ± 0.004
0.5–10 Hz	0.210 ± 0.011
0.5–5 Hz	0.249 ± 0.002

We suspected that the D-Vector model extracted the individual phone sensor biases as features to discriminate between subjects and phones [4]. To test this hypothesis, we trained a model with only accelerometer and gyroscope data labeled *phone_on_table* from the ExtraSensory dataset. This data should not have any user-distinguishing features. If the model is successful in performing verification, it would clearly demonstrate our approach is using the wrong features due to their incidental correlation with subject identity. Table 1 shows the results of these experiments, giving the EERs achieved by the models using different periodogram frequency bands. The first row of the table clearly shows our approach can find and use sensor bias as a feature, confirming our hypothesis.

After concluding that phone specific features inflated our results, we investigated our data processing pipeline and found a mistake. Our preprocessing of the data included the 0 Hz (Hz) term, or bias term, which provides the model a strong signal of sensor bias, in the form of sensor offsets. This term should not have been included. After removing the term, however, the second row of Table 1 shows that the D-Vector approach did significantly better, not worse, at performing verification. We performed additional experiments to determine what frequency bands the sensor bias persist in. Table 1 shows that verification performance of our approach did not degrade for *phone_on_table* until we removed high-frequency bands from the data. Unfortunately, the subject-specific information used by D-Vectors to differentiate subjects also exists at those higher frequencies, so filtering them out from the data is not viable.

The solution to this problem became clear when we reconsidered the tasks given to the approach. For the cases of *sitting* and *phone_on_table,* we were asking the algorithm to extract features from signals that resemble the ones shown in the right graph of Fig. 1.

The only distinctive features in that data are the unique minor deviations of the individual sensors, so the model can discover it and find it. Whereas, in high-activity data, such as the *walking* shown in the left graph of Fig. 1, the small deviations caused by sensor biases are overwhelmed by the broad motion signals. In that case, D-Vectors is using the motion data to perform verification as intended and designed by our experimental setup. The solution, as it turned out, is to not have the approach perform an infeasible task and attempt to learn to discriminate between subjects using inactive data. By applying an energy filter on the data, we were able to limit the significance of sensor bias in the training data and mitigate this issue.

5 Discussion

Similar issues to the ones we described in this paper are likely prevalent in human factors research. It is important that researchers be aware of and avoid these pitfalls. By using a simple threshold, we determined that the labels in ExtraSensory, specifically *walking*, are not reliable enough to be used as ground truth for model training. Public datasets like ExtraSensory are valuable and useful; however, the fact that 85% of the data are labeled post activity [17], and given that humans struggle to neatly segment into minute-long intervals, it is prudent to avoid relying on the labels. Even with the label complications, we cannot understate the value of ExtraSensory because of the breath and realism for studying real-world performance of algorithms. Still, practitioners should be aware of the limitations of the data and be careful in designing experiments and verifying conclusions. Unfortunately, studies using the ExtraSensory dataset make this very mistake [6–10], while studies on ways to mitigate inaccurate labels, for example by using visual analytics to identify them [18, 19], or by accounting for temporal imprecision [20], are vanishingly rare in the context of human activity recognition. This problem can compound when newer models attempt to address specific limitations in older ones [9, 21, 22].

Additionally, steps should always be taken to validate results and decipher what has been learned by deep learning models. We have described a problem faced by all deep learning researchers that bears extra consideration with human factors research: what did my model learn? In human factors research, learned features are oftentimes not immediately apparent, even under manual inspection. It is therefore critical to both understand what features can be correlated in your data and ensure that your model does not learn these features unintentionally. We have described a scenario in which our model learned device heterogeneities which were incorrectly attributed to users resulting in inflated scores in scenarios where user verification should be impossible (e.g. a user's phone is laying on a table). Due to the immense complexity of deep learning models the features they learn often present as 'black-boxes' which can cause easily misinterpreted positive or negative results.

6 Conclusion

Deep learning is a powerful tool for human factors research that we are confident will lead to many more breakthroughs if it is used carefully. We have described specific challenges that we encountered that are likely prevalent issues facing other researchers.

Researchers must understand the practical limitations of the datasets they use, whether it is clean laboratory data or data collected in the wild. Deep learning models can perform complex tasks on human factors data but are difficult to interpret and verify. It is our hope that others can learn from these experiences and avoid similar pitfalls.

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Addressing Two Central Issues of Team Interaction Dynamics: The Whole is Greater Than the Sum of Its Parts

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Abstract. In successful teams, each team member has a distinct taskwork based on individual task roles and responsibilities. Each team member effectively interacts with one another and the technology with which they must interact during the task. Both taskwork and teamwork have situational propensities and entail both ontic and epistemic aspects; thus, understanding how they affect teammates' taskwork and teamwork becomes crucial to fathom the emergence of team coordination dynamics. This paper conceptually discusses the application of quantum cognition to team coordination; how this approach can improve the understanding of the notion of the whole. The open system model, which incorporates both classical and quantum probability descriptions of a system, is reviewed to describe both ontic and epistemic uncertainty. The open system model's contributions to the entropy of an entangled whole are discussed. Lastly, the conceptual differences between sensing and interaction and the experimental scenarios to study these differences are delineated.

Keywords: Artificial Intelligence · Human-autonomy teaming · Decision making · Team coordination · Teamwork · Uncertainty

1 Introduction

A "team" is a sociotechnical system in which two or more heterogeneous and interdependent team members, either human or non-human (e.g., animal, machine), promptly interact with one another in response to information flow and action from one team member to another while adapting to the dynamic task environment to achieve common goals. Being a team necessitates having effective interaction (i.e., communication and coordination) between the team members and maintaining interactive decision-making both at the individual task and team levels.

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Each team member is assigned specific roles [14], requiring effective communication and coordination with other team members to accomplish a team goal. In successful teams, each team member: (1) has a distinct taskwork based on individual task-role related responsibilities; and (2) also effectively interacts with other team members [15] and with the technology to demonstrate good teamwork. These two critical aspects of being a team are taken into account as taskwork and teamwork, respectively. More specifically, taskwork is each team member's task role-related responsibility [16], which involves each team member's task-related judgments/decisions. On the other hand, teamwork is a set of team members' behaviors as a function of coordination requirements imposed by interdependent role-related tasks to achieve the common goals. Both taskwork and teamwork have situational propensities. Since all situations entail both ontic and epistemic uncertainty, understanding how they affect teammates' taskwork and teamwork become crucial to fathom the emergence of team coordination as a whole.

Hitherto, team cognition theories have had two perspectives: (1) "shared cognition," which considers team cognition as the sum of individual knowledge [1] and assesses via shared mental models [2] within the mind; and (2) "interactive team cognition," which defines team cognition as an evolving interactive process within the state of knowledge [3] and assesses via nonlinear dynamical systems modeling [4]. Neither of these perspectives can fully capture the quirks of team coordination behavior due to the limitations of the commonly used theoretical tools based on classical probability theory. This study argues that an improved understanding of team coordination behavior can be obtained by leveraging the findings of quantum cognition [5].

The structure of the paper is as follows. First, we introduce two decision scenarios with a toy model in the context of human-autonomy teaming. Using these decision scenarios, we discuss two types of uncertainty, ontic and epistemic, how these two can affect a decision process. Next, we review the differences between classical and quantum probability theories and then highlight the open system modeling as a way to improving the team cognition theories. Finally, we conceptually introduce interaction phenomenology and discuss its contributions to interactive team cognition.

2 Team Task and Uncertainty: A Toy Model

Suppose a Human-Autonomy team (HAT), consisting of three heterogeneous and interdependent team members: Alice, a human decision-maker; Bob, a specific decision support human-persona; and Sponge (Artificial Intelligence - AI), a specific decision support AI-persona. These two decision support personas are separated based on their taskwork-specific knowledge. In the HAT, each team member's taskwork may involve judgment, choice, and interaction with each other, technology, and the task environment.

The HAT monitors a group of aliens on a far distant planet on which the U.S. Space Force's (USSF) ground units conduct a space mission on the planet. According to the intelligence report, there are two categories of aliens on the planet, "X" and "Y". A category "X" alien is more likely to attack the USSF ground units; a category "Y" alien is more likely to act friendly to the ground units. The team's responsibility is to notify the ground units as early as possible so that the ground units can either withdraw "W" or attack "A" an approaching alien. Due to the aliens' cross-categorical facial features, their images can generate bistable perceptual stimuli; hence, an “X” could look like “Y” and vice versa. Each team member has access to various information based on their task, and all have continuous access to a common operating picture (COP) that shows the area where the aliens approach the ground units.

In the HAT, Alice can notify ground units without interacting with Bob or Sponge. In the first *Scenario-1*, Alice makes a decision without interacting with any of the teammates; suppose that her decision (W), as shown in Fig. 1a. In *Scenario-2*, Alice utters her category choice (X) to Bob or Sponge, and then decides (W), shown in Fig. 1b. The principal difference between these two scenarios is that in *Scenario-1*, Alice maintains her indecisiveness concerning the category of the approaching alien, whereas, in *Scenario-2*, she utters her choice and resolves the indecisiveness concerning the category choice.

These two decision processes were tested with a plethora of studies [5–14]; the results demonstrate a systemic violation of the total probability for the condition in Fig. 1a. This violation is due to the ontic uncertainty –mental indecisiveness– that influences the subsequent decision in Fig. 1a but does not influence the decision in Fig. 1b because ontic uncertainty is resolved by uttering a category choice.

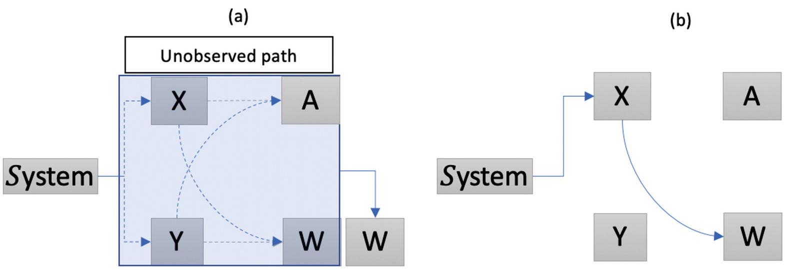

Fig. 1. Path diagram representations of two decision scenarios: (a) the condition in which there is no observation, and the choice of outcome is “W”; and (b) the path that is taken is known, and the choice of outcome is “W.”

There are always ontic and epistemic aspects of a system in any situation. Ontic states of a system are referent of individual descriptions of a system (i.e., state of reality) [15]. Epistemic states of a system describe the others’ knowledge of the system’s properties (i.e., state of knowledge). These two states give rise to different types of uncertainty, ontic and epistemic, allude to levels of team coordination dynamics. Epistemic uncertainty can be resolved by obtaining more information about the system [16]. However, no extra information can be obtained to reduce ontic uncertainty; it can only be resolved when the system interacts with the environment.

The distinction between the two can be articulated by re-visiting the toy example. In Fig. 1a, Alice is in an indefinite mental state, neither “X” nor “Y,” concerning the category of alien. Due to her indecisive mental state, Alice’s cognitive system entails ontic uncertainty. This ontic uncertainty can only be resolved if Alice utters her choice of category. Therefore, in the case of Fig. 1a, since the ontic uncertainty is not resolved, it influences her subsequent decision. On the contrary, in Fig. 1b, since the ontic uncertainty is resolved, the influence that occurs in Fig. 1a vanishes.

Typically, the effects of an interaction between Alice and Bob or Sponge are scrutinized at the epistemic level. However, although a decision, judgment, choice, communication, coordination, or selecting one alternative over another can allude to different meanings, each of these acts should be considered as an interaction between a human cognitive system and the environment. Each interaction alters the human cognitive system as a constructive process. This is different from sensing, which alters –not resolves–ontic uncertainty and does not construct a definite state.

3 Two Ways to Build Models of Human Cognitive Systems

Models of human-cognitive systems are probabilistic and dynamic, and these models support the design of AI. Typically, these models are built and tested with classical probability theory (CPT) or classical logic. However, there are other ways to build and test these models, such as quantum probability theory (QPT) or quantum logic. CPT and QPT are discussed in the following sections, respectively.

3.1 Classical Probability Theory

CPT-based models have two assumptions. The first assumption implies that the system is in a definite state at any time, as shown in Fig. 2a. A judgment/choice becomes akin to a readout or simply recording what existed right before the observation [5]. The definite state assumption (Fig. 2a) engenders an oversimplified understanding of the notion of the state such that it alluded to a static understanding of the concept of the state. The definite state assumption has important implications concerning the notion of entropy because having the system in a definite state implies that someone, at least the system itself, must know this state. If this were true, decision-makers would have experienced no ambiguity [6].

Moreover, classical entropy, a.k.a. Shannon's entropy, is interpreted as unpredictability [6]. This interpretation is associated with epistemic uncertainty; it is assumed that one can reduce the entropy of a system by obtaining more information about the system. However, this may not be the situation for compound systems because the whole, as an inseparable system, emerges as an entropy minimizing system [17], which obeys subadditivity, which is not supported by the classical entropy.

The second assumption is that events are always commutative –A then B = B then A. However, research has demonstrated that commutative assumption is systemically violated –e.g., conjunction fallacy [5]. Thus, attempts to fathom complex team behavior, merely within the rules of CPT and classical logic, can only deliver an incomplete understanding of this complex phenomenon.

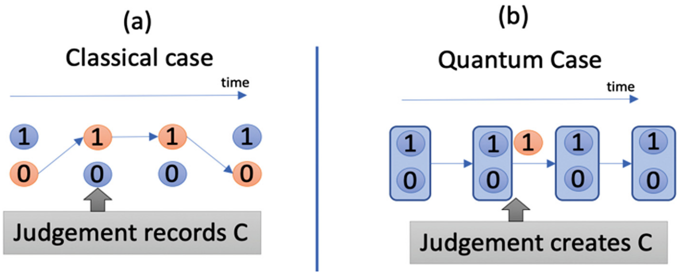

Fig. 2. (a) The classical model of a human cognitive system, although the cognitive system changes from moment to moment, at any time, it is in a definite state with respect to some judgment/choice; and (b) the quantum model, the cognitive system is in a superposition with respect to some judgment/choice.

3.2 Quantum Cognition

Over the last two decades, research efforts in cognitive science demonstrated that quantum probability theory (QPT) could also be used to model human behavior, called quantum cognition. The focus of quantum cognition is to model complex social phenomena by using the mathematical principles of quantum theory. QPT removes some of the restrictions of the CPT. According to QPT [5]: (1) The system is in an indefinite state – as shown in Fig. 2b. superposition state and supports ontic uncertainty; (2) judgment creates a property of the system when the system interacts with an environment; (3) judgments disturb each other, and interference effects can happen, and total probability violations can be observed; (4) cognitive phenomena may not be decomposable and can be explained by entanglement, which means that two or more separate systems behave like one. According to classical entropy, a system's entropy is expressed by adding the subsystems' entropy values. However, if the system state is entangled –e.g., not a separable whole– additivity is violated, and subadditivity constrains the relation between the entropy of the whole and its subsystems [17]. To determine the limits of the whole's entropy concerning its subsystems, by using subadditivity, one can express the triangle inequality [17]:

$$|S(\rho_1) - S(\rho_2)| \leq S(\rho) \leq S(\rho_1) + S(\rho_2) \quad (1)$$

Equation 1 indicates that while the subsystems' (S) entropies (ρ) increase, the entropy of the whole may not increase; and (5) contrary to the classical assumption –complete knowledge of a system means that one can know everything about its parts– in quantum theory, one can know everything about a system and know nothing about its subsystems [18]. A generalized way of modeling team coordination dynamics with QPT may be incomplete, but the open quantum system model can better capture team coordination dynamics.

Open System Model and Team Coordination. An open system model [12] incorporates both classical and quantum descriptions of a system and can describe both ontic and epistemic uncertainty [18, 19]. Thus, it can be used to explicate the causal mechanisms that underlie team coordination effects by considering non-classical correlation, contextuality, entanglement, and non-separability, which cannot be explained with the structures of the CPT.

One of the previous studies categorizes the problems of team coordination under two central issues [20]: (1) where does team coordination occur (within individual mind or between the minds)?; and (2) what are the levels of analyses of team coordination, such as physiological, behavioral. Even if these issues are addressed in team coordination research, they are incomplete to assess team coordination dynamics at the whole level. The theoretical impasse [20] in team coordination is due to CPT premises that enforce a perplex dichotomy between inner mental components and outer relations between them. Quantum cognition can ameliorate this theoretical impasse with the constructivist modeling approach. Specifically, the open system model master equation incorporates the quantum and classical behavior of a system such that the propensities of the situation can be better captured. Research findings indicate that using quantum-classical hybrid dynamics [21] is better at explaining complex phenomena. The open system model master equation can express the time evolution of the system state ρ in Eq. 1, and the limits of Eq. 1 can be operationalized [17] at the team level by expressing a dynamic system state of an inseparable whole, e.g., team.

Interaction Phenomenology and Interactive Team Cognition. Although Interactive Team Cognition (ITC) considers interaction – coordination or communication– as the key enabler of team cognition, interaction phenomenology has not exactly ensued. As articulated thus far, according to QPT, interaction is a constructive process [19], which means that any interaction among team members can produce information. Since the production of information can have consequences beyond the epistemic elements of a system, e.g., transient resolution of ontic uncertainty, a dichotomy between sensing –no physical exchange– and interaction –physical exchange– is indispensable. This distinction is an important step further to assess team coordination dynamics and the understanding of the whole.

There are two systemic consequences, which are apposite to ITC, of Alice uttering her category choice. First, some of the potential information in the system is actualized through interaction. Second, she actively influences her cognitive system by resolving its ontic uncertainty concerning the category choice; in the case of not resolving this uncertainty, Alice's ontic instability will influence her subsequent judgment.

When team members interact, they actualize some of the potential information of the situation [22], which comprises the team and elements of the environment. In part, the actualized information reveals some of the situation's intrinsic properties, which would be otherwise inaccessible. In a simple situation, since the team members have some knowledge of the situation via training, the ensuing interactions do not reveal anomalies because the intrinsic –ontic– instability is minimal and coherent with the epistemic elements. In complex situations, however, when team members come across a roadblock, the team members may not have the conceptual readiness to cope with the emergent element; in other words, team members' ontic instability grows. Since the only way to resolve, transiently, ontic uncertainty is to interact –have a physical exchange– with the environment, elements of ITC demonstrate a coherent, however incomplete, explanation of team cognition. Therefore, we propose using the open system model approach to develop an interaction phenomenology that can ameliorate team cognition.

To use the open system model characteristics in team cognition, rudimentary level experimental and theoretical works need to be done. For example, the two decision scenarios are discussed in Fig. 1 will be studied with the reverse order interaction, from teammates to Alice. The reverse order interaction experimental scenarios are as follows: an alien appears in the area that is surveilled by Alice and her teammates, and Alice needs to notify the ground troops. While Alice is inspecting the image, one of the teammates –Bob or Sponge– sends a message to Alice before she decides – "A" or "W". In this situation, four decision scenarios can accentuate the difference between ontic and epistemic uncertainty: (1) a notification appears on the COP screen, and it indicates that a message is received from Bob or Sponge; the content of the message is not shown without Alice's physical action; (2) a notification appears on the COP screen indicating that a message was received from Bob or Sponge; the content of the message is not shown, but Alice acknowledges seeing the message by a mouse click or verbal utterance; (3) the entire message appears on the COP screen, such that Alice can read it; (4) the entire message appears on the COP screen, such that Alice can read it and acknowledge reading the message with physical activity, such as in the form of a mouse click or verbal utterance.

4 Summary

Being a team requires having effective interaction between the team members and maintaining interactive decision-making at the individual and team levels. To this end, we argue that team coordination assessment is incomplete due to the limitations of the commonly used theoretical and methodological tools. We discussed the differences between classical and quantum probability theories. Then, we reviewed the open system model as a general way to incorporate the ontic uncertainty and how ontic uncertainty can influence subsequent decisions. We discussed entanglement as a way to study the whole as it emerges as an entropy minimizing system state. We argued that constructivist understanding of quantum cognition is promising to improve ITC further. We indicated that conflating uncertainty of possible outcomes with lack of knowledge about the state of a system can result in over-interaction with a machine to obtain more information; in return, over-interaction can negatively affect team effectiveness system can become predictable by others. Therefore, comprehensive team coordination dynamics research is indispensable and can be improved by an open quantum system model.

To understand team interaction dynamics as a whole, considering the ontic and epistemic aspects, is indispensable. Examining both physiological and behavioral measures can bring comprehensive insights into team interaction dynamics using quantum-classical hybrid dynamics [21] and nonlinear dynamical systems methods [23]. For instance, the cognitive-behavioral and -neurophysiological levels of analysis can explicate the changes in both ontic and epistemic uncertainty when team members counter novel situations.

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Amyotrophic Lateral Sclerosis Disease Progression Presents Difficulties in Brain Computer Interface Use

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Abstract. Brain Computer Interface (BCI) systems potentially provide those with disabilities an alternative means to communicate and control their environment, increasing independence and quality of life. The goal of our study was to examine the effect of disease progression on the efficiency of communication using a P300 BCI speller. To address this, BCI data was analyzed from 19 people living with ALS at various stages of disease. Accuracy in word spelling showed significant correlation to ALSFRS-R score, a measure of disease severity and worsening function, with decreased accuracy as the disease progressed. This decrease in accuracy may be attributed to system components and methodology that lead to an increase in fatigue for people with less function, but alternatively may be due to the progressive changes in neural networks as the patient progresses. Adjustments to BCI systems, use of alternative event potentials, or alternative technologies may be necessary to optimize BCI use in ALS.

Keywords: Brain computer interface · ALS · Assistive technology · Neuromuscular disease · EEG · ALSFRS-R · AAC

1 Introduction

Amyotrophic Lateral Sclerosis (ALS) is a progressive disease characterized by neurodegeneration in the brain and spinal cord [1]. Affected individuals experience loss of voluntary muscle movement including the ability to speak and move independently. The need for alternative and augmentative communication (AAC) and assistive technology increases as the disease advances and physical capability decreases. The inability to use

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natural speech to communicate affects 80 to 95% of people with ALS [2]. This deterioration can occur rapidly and at various stages of the disease, depending on the individual [2]. Therefore, an ideal AAC solution needs the flexibility to function even as the disease progresses. People with ALS can progress to a state of being locked in and unable to speak or move, despite being cognitively aware [3]. At this advanced stage, a BCI can not only provide a solution that maintains communication, but also has the potential to be used for environmental control that will enhance independence and improve quality of life. However, first and foremost, adequate communication is vital in maintaining social aspects of everyday life.

Assistive technologies such as modified computer mouses, styluses, and switches are devices that allow access to AAC [4]. Devices that utilize eye tracking, such as Eyegaze and Tobii Dynavox, do not require as much movement [4–6], but do require frequent calibration and are fatiguing. Brain computer interfaces (BCI) further reduce the physical barrier for AAC [4]. BCI technology most commonly utilizes electroencephalography (EEG), a wearable and noninvasive modality to record brain dynamics [7]. EEG based BCIs can utilize the oddball paradigm via event-related potentials (ERP) to make letter or icon selections for spelling or environmental control, respectively [8]. In summary, brain signals are recorded, analyzed, and transformed into commands and outputted actions [9].

Specifically, we are interested in the use of non-invasive EEG BCI systems using P300 event-related brain signals. The P300 is a widely demonstrated brain potential that is elicited about 300 ms after a target stimulus, as demonstrated during the oddball paradigm [10, 11]. It is characterized by a large, positive peak [11]. To provoke the P300 response, the user must be able to differentiate between the target and non-target stimuli [10]. For example, a letter when it flashes versus when it does not. P300-based BCI systems are widely used in the field, ranging from typing text [12], to internet browsing [13], and virtual environment navigation control [14]. This system was first introduced by Farwell and Donchin in 1988, with the idea of aiding communication for locked-in patients [10].

P300-based BCI systems have demonstrated feasibility for use by individuals with ALS [15–17]. While McCane et al. (2015) reported that ALS performance is similar to that of healthy control participants [18], others have reported difficulties with BCI use. In some severely disabled users, visual impairment can lead to difficulty in BCI use [16]. Furthermore, some studies have reported that visual BCI use causes less eye strain than that of eye-tracking AAC devices [19, 20], while others have recognized an increased amount of effort and fatigue accompanied by BCI systems [21]. BCI use requires selective attention and certain levels of working memory and cognitive load, contributing to effort required by the user and possible subsequent fatigue [4, 19].

The potential of BCI technology to increase independence by providing a new avenue of access to communication and environmental control is significant, with successful at-home BCIs having shown to increase quality of life [20]. As neurodegeneration progresses, there may be increasing difficulties with attention and working memory as well as cognitive loads. Because of this, we set out to examine the effect of ALS disease progression on the efficiency of communication using a BCI speller. In addition, we wanted to determine whether this is a practical and realistic means for individuals with ALS to communicate or control their environment. To do this, we looked at the complexity of the system and the degree to which the participants were able to use it.

2 Methods

Patients with definite or probable ALS by El Escorial Criteria were recruited from the MDA ALS Center of Hope at Drexel University College of Medicine [22]. A total of 19 ALS participants were enrolled in this study (8 women and 11 male). The average age was 57.5 (30–73 range). The average ALSFRS-R score was 25.9 (9–44 range). The average time since diagnosis was 23.2 months (0–45 range). The protocol for this study was approved by the Drexel University Institutional Review Board. Informed consent was received from all participants. Participants were required to be 18–80 years of age and diagnosed with ALS. Participants with difficulty seeing the letters on the screen or had cognitive impairments that would inhibit the ability to follow instructions were excluded.

Participants were asked basic demographics questions including name, date of birth, race, gender, and handedness. In addition, disease characteristics including time since diagnosis, age, and the revised Amyotrophic Lateral Sclerosis Functional Rating Scale (ALSFRS-R) score were collected. The ALSFRS-R is a 12-item scale based on functional ability of the subject in four major domains: fine motor, gross motor, bulbar and respiratory. Each item is rated on a scale of 0–4 with a score of 4 indicating normal function and a range of scores of 0–48. Therefore, a higher score indicates better function. This score has been shown to decrease an average of 1.02 points per month over time and is a surrogate marker of severity and progression [23].

Table 1. Subject demographics and disease characteristics

N	19
Age (years)	
Mean ± SD	57.5 ± 11.1
Range	30–73
Sex	
Female/Male	8/11
Time since diagnosis (months)	
Mean ± SD	23.2 ± 14.6
Range	0–45
ALSFRS-R score	
Mean ± SD	25.9 ± 11.7
Range	9–44

2.1 Equipment

Our BCI system consisted of BCI2000 software [24] on a Lenovo ThinkPad laptop computer (Windows 7), a 16-channel g.USBamp biosignal amplifier (g.tec medical), 15.5 in. (diagonal) monitor, and wet electrode cap (Electro-Cap International, Inc.) with clear electrode gel. Electrodes were located at locations F3, Fz, F4, T7, C3, Cz, C4, T8, CP3, CP4, P3, Pz, P4, PO7, PO8, and Oz, based on the 10–20 System for EEG [25] (See Fig. 1).

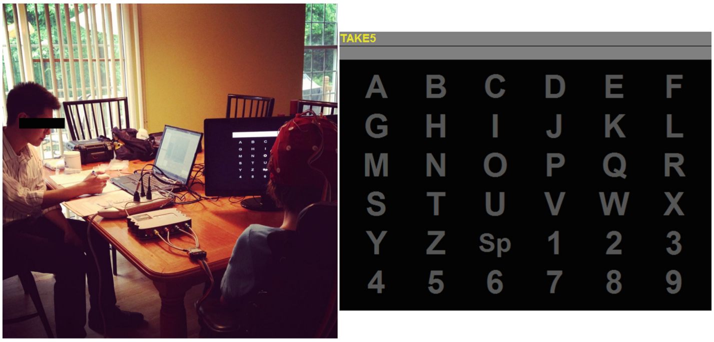

Fig. 1. A representative BCI system set-up at a participant's home (left). The BCI 6 × 6 letter matrix that was displayed on the screen (right).

2.2 Protocol

BCI sessions were conducted at the participant's home or at the clinic located at the outpatient Neurology Department at Drexel University College of Medicine. One session per participant was conducted. Participants sat in a chair or wheelchair about three feet away from the monitor screen. A speller board flashing in a checkerboard paradigm (CBP) was used [26]. CBP matrix flashes at random, as opposed to the standard row/column paradigm (RCP). A 6 × 6 letter board was used (Fig. 1). Participants were instructed to attend to or count the number of times that the letter flashed in the matrix. Five calibration words (TAKE5/3PIGS/QUICK/ZONE4/9MILE) and five test words (58VEX/DAFT1/ZEBRA/PICK6/3g) were spelled. Only the test words (25 letters, or trials) were used in calculating BCI accuracy. A sampling rate of 256 Hz was used along with 58/62 notch, 0.5 Hz high-pass, and 30 Hz low-pass filters. The Matlab-based P300GUI tool was used to train and test the linear classifier for detection of P300 ERPs [27].

3 Results

BCI accuracy ranged from 32 to 100% (73.9% average ± 20.9 SD). This consists of the five words spelled after calibration, or 25 trials/characters (copy-spelling). Accuracy was calculated by the total number of letters correctly spelled with the BCI divided by the total 25 letters attempted. Participants were not given multiple attempts if an incorrect letter was outputted.

A multiple linear regression was performed to examine the variation in BCI accuracy and to determine if there was a correlation with any of the ALS disease related characteristics (ALSFRS-R score, time since diagnosis, and/or age). The results demonstrated a correlation of BCI accuracy with the level of function as measured by the ALSFRS-R score (Fig. 2, $p = 0.005$, $r = 0.38$). Percent correct did not show significant relation to time since diagnosis ($p = 0.41$) and age ($p = 0.15$). This suggests that as the severity of disease progresses and function decreases, which is measured by the ALSFRS-R [28], the ability to use this BCI system does as well.

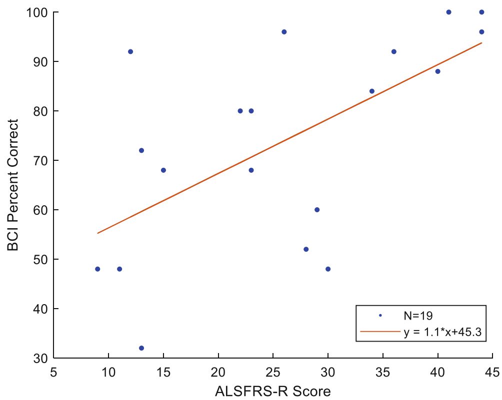

Fig. 2. BCI accuracy versus ALSFRS-R score.

4 Discussion

Our findings agree with similar studies that suggest that persons diagnosed with ALS can use a P300 based Brain Computer Interface system [15–18, 20, 29]. Multiple studies suggest at least a 70% performance level as the minimum needed for language support [29–31]. More than half of our participants reached accuracy levels greater than 70% (n = 11), with two additional participants at a 68% accuracy level.

In comparing three variables (age, time since diagnosis, ALSFRS-R) with BCI accuracy, only ALSFRS-R score showed significant correlation. Our data suggests that a decrease in ALSFRS-R score, or increased disease progression, decreases BCI accuracy for people living with ALS. While this finding is supported by findings in some studies [32, 33], it is inconsistent with others [16, 31]. This variation in results may have several explanations including differences in design and style of target presentations (i.e., CBP, RCP).

Given that decreased accuracy is correlated with disease progression and severity, we believe some of the decreased accuracy can be attributed to the system components and methodology used since aspects of this traditional BCI system can lead to an increase in fatigue for people with less function. P300 based BCI spellers require the user to recognize and selectively attend to the intended letter among many other stimuli [4]. Characteristics of ALS disease progression suggest that this may become increasingly difficult at later stages. 44–83% of ALS patients report fatigue, with sleep disruption, functional status, and other confounding symptoms being the cause [34]. Fatigue may reduce the user's attentional capabilities, which can subsequently reduce P300 amplitude [35]. Fatigue of the eyes can contribute to decreased BCI accuracy. McCane et al. reported visual impairment as a distinctive characteristic of ALS participants with low BCI accuracy (under 40%) [16]. ALS has been shown to affect gaze fixation and stability in some [36]. Furthermore, many individuals with little to no motor ability lay in a bed or reclined position, as opposed to being upright in a wheelchair or seated posture. This presents difficulty in using a BCI, as the user needs to look ahead at a screen. Fatigue can occur as a result of having to strain the eyes when staring at the screen for an extended period of time. Pain and muscular fatigue may also happen when the user's head is propped up. In patients with ALS, pain of the extremities, neck, back, and trunk is commonly reported [34].

Other studies describing BCI use difficulties for late-stage patients suggest neurodegeneration in non-motor areas of the brain [32] and cognitive alterations for those in a locked-in state [37] as contributing factors. This type of degeneration, if affecting the individual's ability to cognitively recognize a visually evoked potential, or hindering the P300 ERP, could result in BCI use difficulties. Further understanding about non-motor neurodegeneration in later stages of ALS and the effects on related ERPs may indicate the most efficient and accurate BCI system [32].

Overall, current BCI systems still necessitate a high dependence on caregivers. Set-up time and calibration lead to extended sessions that can exert what little energy the user has. Furthermore, although the system used here is portable, the size of equipment and number of wired connections is not ideal for use outside of a clinic or home setting (Fig. 1). Scaling down current BCI systems could increase practicality and scope of use, subsequently increasing independence for ALS individuals. Improving both ERP decoding models and speed of translation could also lessen fatigue. This could make users more comfortable by providing a more efficient system.

From the data collected in this study, our team has focused on adapting our current BCI technology to address these shortcomings, all of which can contribute to user fatigue. By integrating new technologies such as augmented and virtual reality glasses and switch devices [2], the need to strain towards a computer monitor or depend on a caregiver may be able to be reduced.

5 Conclusion

Brain Computer Interface systems increase independence for disabled persons with ALS by providing motor-free access to communication and environmental control. Our data suggests that disease progression may hinder BCI accuracy and hence its use. We suggest that by reducing fatigue elicited by BCI equipment setup, interface, and engagement, we may be able to address this issue. As a result of this study and the challenges that current

BCI technology does not address, our team is working to find ways to better adapt BCIs for persons with ALS.

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Epileptic Seizure Detection Using Tunable Q-Factor Wavelet Transform and Machine Learning

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Abstract. Epileptic seizures constitute an important group of neurological disorders in brain that affect many people globally each year. Complexity of EEG signals due to their high-dimensional nature, as well as artifacts in data due to equipment flaws, pose significant challenges to physicians in diagnosing epileptic seizures directly and manually from EEG signals. In this paper, a method is proposed to combine signal processing and machine learning for diagnosing epileptic seizures and tested on the Bonn University database. We used Tunable Q-Factor wavelet transform (TQWT) method to transform signals. Subsequently, various statistical properties, frequency, chaotic and fractional were extracted from the TQWT sub-bands. Subset selection techniques were used in order to reduce the features of the methods used and their results were compared. Finally, a SVM method with different kernels were tested, where the empirical results show the high efficiency of the proposed method in the diagnosis of epileptic seizures.

Keywords: Epilepsy · Seizure detection · Electroencephalogram (EEG) Signal · Feature extraction · Fractional order modeling · Tunable Q-Factor Wavelet Transform · Machine learning

1 Introduction

Epilepsy is a chronic brain disease that affects around 50 million people worldwide. This disease is characterized by recurrent seizures, which are brief episodes of involuntary movement that may involve a part or the entire body and are sometimes accompanied by loss of consciousness. Seizure episodes are a result of excessive electrical discharges in a group of brain cells. Different parts of the brain can be the site of such discharges. Seizures can vary from the briefest lapses of attention or muscle jerks to severe and prolonged convulsions. Seizures can also vary in frequency, from less than 1 per year to several per day. Seizure prediction systems can be life changing for patients with epileptic seizures. By accurately identifying the periods in which seizure occurrence has a higher chance of happening we can help epileptic patients live a more normal life. So far, various methods have been proposed to diagnose epileptic seizures, among which

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EEG recording is especially popular among physicians. EEG signals record the electrical activity of brain during a variety of neurological disorders. Despite the significant benefits of EEG recordings, their analysis is time consuming and complicated. As such, automated techniques for diagnosing epileptic seizures can be very impactful.

The accuracy of such techniques relies heavily on the algorithms used to extract features that can be analyzed using the classical machine learning methods. Methods of feature extraction in EEG signals for the detection of epileptic seizures include time-domain, frequency, time-frequency, and ultimately nonlinear techniques [1]. Time domain transformations are perhaps the most natural representation. Examples include features extracted from autoregressive (AR), moving average (MA), and autoregressive moving average (ARMA) models [2, 3]. In this approach, a time domain model is estimated from the sample, and the coefficients are extracted as features to be used by the machine learning algorithm. The frequency domain of a signal (i.e., time series) often contains more information about its characteristics. Wavelet transforms (DWT, CWT) and Fast Fourier transform (FFT) are the most widely used frequency domain techniques.

Due to the chaotic nature of EEG signals, it has been shown that nonlinear feature extraction methods are more effective than other methods. The most important methods for extracting nonlinear properties include a variety of fractal models, fractional theory as well as entropies. The following is a review of a number of studies on the detection of epileptic seizures based on EEG signals. The authors in [4] used DT-CWT and FFT methods for signal decomposition and feature extraction, in an attempt to diagnose epileptic seizures in Bonn University dataset and used KNN as a classifier. The reported results show high accuracy. In reference [1] DTCWT-based epileptic EEG signals classification algorithm is presented which, after decomposing and obtaining the sub-bands, three nonlinear features including Hurst power, fractal dimension, and permutation entropy are extracted as attributes and finally for classification were given to SVM. In [5] the authors compared 50 different features for epileptic seizure detection in EEG signals, chosen from various domains, namely, time and frequency. Additionally, they used non-linear ones to improve system performance. Finally, they used Convolutional Neural Netwroks with Auto-Encoder (CNN-AE) for classification [6]. In this paper, we study the application of TQWT for adaptive feature extraction from EEG signals, which are then used by machine methods for classification. We use the dataset made available by the Bonn University in Germany to assess our model's accuracy. The empirical results suggest that the proposed methodology results in competitive prediction accuracy in detecting epileptic seizure from EEG signals. The rest of the article is organized as follows. In Sect. 2, the proposed method and dataset are introduced. The Sect. 3 provides the details of a case study using the Bonn dataset. We conclude our paper with a discussion in Sect. 4.

2 Data and Methodology

In this paper, a new method of diagnosing epileptic seizures using TQWT and combining the characteristics of different areas is presented. Figure 1 presents an overview of the proposed methodology. Using the Bonn dataset, TQWT is used to preprocess EEG signals. Next, in the feature extraction step, the properties of different domain properties from each TQWT subband are calculated. In the fourth step, the deep auto-encoder (AE) method for feature reduction is used. Finally, two classification algorithms, SVM and KNN, have been used. In the following sections, we describe each step in detail.

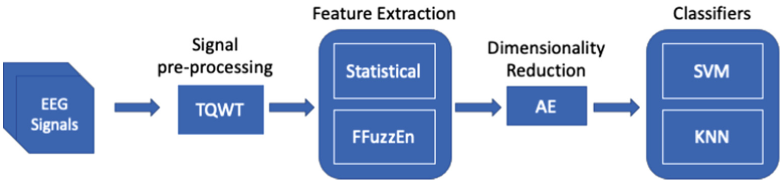

Fig. 1. Overview of the proposed methodology

2.1 Bonn Dataset

In this work, we use the dataset described in [7]. This public dataset is provided by the University of Bonn and is one of the most commonly used datasets for epileptic detection studies. It consists of 5 sets, typically labeled from A to E, each consisting of 100 single-channel recordings. In what follows we provide a brief overview of each dataset. For a more detailed discussion, the reader is referred to [7]. Datasets A and B consist of EEG measurements obtained from five healthy adult volunteers. In the former dataset volunteers were awake with their eyes shut, while it was open in the latter. The electrode placements followed the standard 10–20 placement scheme. The signals from these two datasets are regarded as representing the "normal" conditions. In contrast, the other three datasets were recorded from five presurgical epileptic patients. Datasets C and D only contain activities measured during seizure free time periods. Segments in C were recorded from the hippocampal formation of the opposite hemisphere of the brain, while segments in D were recorded from the epileptogenic zone. Dataset E only contains seizure activity.

The rest of this section describes the TQWT technique and features extracted from TQWT subbands. First, we describe TQWT and its characteristics. Then, we extracted a variety of statistical and nonlinear features. The statistical features include the first 4 statistical moments (mean, variance, skewness and Kurtosis). We used fractional fuzzy entropy (Sect. 2.3) in order to augment our features with nonlinear properties of the signals.

2.2 TQWT

The Q-factor of an oscillatory pulse is defined as the ratio of its center frequency to its bandwidth, i.e. $Q = \frac{f_c}{B}$. This relationship implies that the sustained oscillation cycle signal, which is narrow bandwidth, has high value of Q-factor. The TQWT method was first introduced in 2011 by Selesnick [8]. It helps in decomposing a signal into oscillatory and transient components. Ideally, the choice of Q factor of a wavelet transform should depend on the oscillatory behavior of the signal [9]. A wavelet transform with a low

Q-factor should be used for transient non-oscillatory signals, while the high Q-factor is better suited in analyzing oscillatory signals. The TQWT can be realized by the band pass filter. It is implemented by applying two channel filter banks whereby the low-pass and high-pass scaling parameters are defined by α and β, respectively, as follows:

$$\beta = \frac{2}{Q+1}, \quad \alpha = 1 - \frac{\beta}{r}$$

Where Q and r are Q-factor and redundancy parameters of TQWT. The redundancy parameters r is the total number of wavelet coefficients divided by the length of the signal to which the TQWT is applied. A third parameter j is also used to dictate the number of decomposition levels.

2.3 Fractional Fuzzy Entropy

For a given time series $\left\{ x^N(n), n = 0, 1, 2, \ldots, N-1 \right\}$, FuzzyEn can be defined by

$$FuzzyEn\left(m, r, x^N\right) = -\ln \frac{\phi^{m+1}(r)}{\phi^m(r)}$$

Where m is the dimension, r is the similarity tolerance, and $\phi^m(r)$ is constructed based on similarity degree between $X(i)$, which represents m consecutive x values, and $X(j)$ with $i = 1, \ldots, N-m+1$. An extension of FuzzyEn is by taking the advantage of fractional order derivative concept, which proves advantages to extract more information from the signal.

The combination of fuzzy entropy and fractional information concept resulted in fractional fuzzy entropy (FFuzzyEn) method [10]. FFuzzyEn showed competitive performances in non-linear time series measurement. It was also observed the complexity changes of EEG data in analyzing for both epilepsy patients and healthy controls. During the seizure, the complexity was the lowest for the patients with epilepsy and during seizure-free intervals; the complexity is lower in comparison to the healthy persons. FFuzzyEn is used in the biomedical and physiological analysis of EEG data. The algorithm employed four parameters, sequence length N, tolerance r, dimension m, and reconstruction fractional-order α. ψ represents digamma function, ϕ^{m+1} represents exponential function. FFuzzyEn is formulated as below by applying fractional order information concept.

$$FFuzzyEn\left(m, r, \alpha, x^N\right) = -\left(\frac{\phi^{m+1}(r)}{\phi^m(r)}\right)^{-\alpha} \frac{\ln \frac{\phi^{m+1}(r)}{\phi^m(r)} + \psi(1) - \psi(1-\alpha)}{\Gamma(1+\alpha)}$$

FFuzzyEn is equivalent to fuzzy entropy when $\alpha = 0$.

2.4 Auto-encoder

To reduce the size of the feature matrix, feature reduction methods are used. In classical machine learning, typically the Principal Component Analysis (PCA) method is used for dimensionality reduction. Autoencoder networks (AE), extend PCA by extracting *nonlinear* features of the input. In this type of network, the input features are the same as the output ones, but the number of hidden variables is substantially fewer than the input, which allows the network to learn a low-dimensional representation of the input. In this work, we have used an AE network as described in [11] to reduce the number of features by using 2 hidden units. More details about AE techniques are given in [5] (Fig. 2).

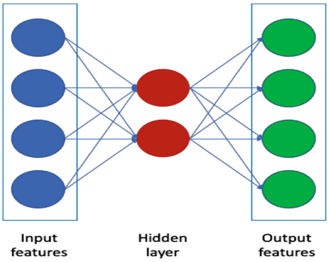

Fig. 2. Structure of a single layer auto-encoder

2.5 K Nearest Neighbor

KNN is a supervised learning algorithm which despite its simplicity can be very effective. This model simply, for each data point, measures the distance to the other nearby data points in the training dataset. As such, the key algorithm choice is the function used to measure the dissimilarity between data points. The most common choice is the Euclidean distance: $\sqrt{\sum_{i=1}^{k}\left(x_i - x_j\right)^2}$ where x_i and x_j are two different points. A drawback of this algorithm is that it requires the whole dataset for each iteration, as such it can be very memory intensive.

2.6 Support Vector Machines

SVMs are a class of supervised machine learning algorithm, which have witnessed significant success in dealing with small and medium datasets. SVMs generalize the inner product to kernelized dot products, which effectively transforms the data to a higher dimensional space, which simplifies the classification task. This process is called the “Kernel trick”. An attractive characteristic of this method is that the solution does not rely on all data point, rather just those the belong to the “support vector”. For a two-class problem, given a training set $\{x_k, y_k\}_{k=1}^{N}$ with input data $x_k \in R^n$ and output data $y_k \in R^n$ with class labels $y_k \in \{-1, 1\}$, we can consider the following linear classifier:

$$y(x) = sign\left[w^T x + b\right]$$

Where w and b are parameters to be estimated from data. In order to tolerate small misclassifications, the optimal separating hyper-plane should satisfy the following condition:

$$y_K\left[w^T x_k + b\right] \geq 1 - \xi_k, \quad k = 1, \ldots, N$$

where ξ_k are slack variables, and $\xi_k > 0$.

The prediction function y(x) can be represented as

$$y(x) = sign\left[\sum_{k=1}^{N} \alpha_k y_k K(x, x_k) + b\right]$$

where α_k are Lagrange multipliers, $K(x, x_k)$ is the kernel function. The most common kernel choice is the RBF kernel, which can be written as

$$K(x, x_i) = \exp\left(\frac{-|x - x_i|^2}{2\sigma^2}\right)$$

where σ controls the width of RBF kernel.

3 Results

The results of the proposed method are presented in this section of the article. Matlab 2019b software has been used to implement the proposed method. Researchers have shown that a 5-frame Bonn dataset EEG signals performed better than other time frames [5]. Therefore, in this section, all the results presented are 5 s per time window. In this paper, after windowing the signals to 5-s intervals, the TQWT wavelet converter is used to decompose EEG signals into different frequency sub-bands. In order to use the TQWT wavelet converter, the toolbox provided in [12] has been used. TQWT has three important parameters r, Q and J that are similar to the references [13] selected 3, 1 and 8, respectively. As can be seen, the parameter J = 8 is selected, which means that it produces 9 levels of parsing for each frame of EEG signals. In the feature extraction stage, the number of features extracted from each frame is equal to the number of wavelet decomposition levels (J = 9) multiplied by the total number of features. Therefore, for each frame of the EEG signal, different features include statistical and non-linear are obtained. In order to reduce the features, the AE method is investigated. Finally, rbf-SVM, linear SVM and KNN (for different K) classification algorithms were used. The following Table 1 shows the evaluation parameters of the proposed method for different classification algorithms.

As can be seen, the rbf SVM classification algorithm has an average accuracy of 99.42 per classification problem of the two classes A-E, B-E, C-E, D-E and ABCD-E. Also, this classification method has a better performance compared to other classification methods in the AB-CD-E three-class problem classification, and it can be seen that 99.53 have been obtained.

Table 1. Accuracy results of classification algorithms per different time window

Methods	Sets	Accuracy	Precision	Spec	Sens	F1-Score
RBF SVM	A-E	99.58	99.48	98.50	99.62	98.50
	B-E	99.62	99.26	99.25	99.31	99.23
	C-E	98.91	99.76	99.75	99.85	99.25
	D-E	99.87	100	99.87	99.82	99.80
	ABCD-E	99.15	98.94	98.25	97.83	97.59
	AB-CD-E	99.53	98.98	97.95	98.60	99.06
Linear SVM	A-E	99.30	97.76	98.75	98.25	98.00
	B-E	99.27	99.00	99.03	99.10	99.02
	C-E	99.12	98.97	98.75	99.44	99.12
	D-E	99.90	99.75	100	99.95	99.87
	ABCD-E	99.04	98.82	99.11	97.25	96.88
	AB-CD-E	98.62	98.25	97.50	98.65	98.45
KNN (K = 3)	A-E	99.20	98.04	98.12	100	99.08
	B-E	99.18	98.04	98.10	100	99.01
	C-E	96.56	95.15	98.06	98.22	96.58
	D-E	94.50	94.06	97.95	95.13	94.55
	ABCD-E	92.20	91.49	92.49	95.47	95.36
	AB-CD-E	95.80	95.50	97.83	95.51	95.60
KNN (K = 5)	A-E	99.00	98.04	98.10	99.96	99.02
	B-E	99.00	98.04	98.08	99.90	99.02
	C-E	96.56	95.15	98.19	98.11	96.53
	D-E	94.50	94.06	97.00	95.32	94.51
	ABCD-E	92.20	91.49	97.66	95.54	95.32
	AB-CD-E	95.80	95.50	97.83	95.52	95.49

4 Conclusion

In this paper, an automated method for the diagnosis of epileptic seizures on EEG signals using signal processing and machine learning techniques is presented. The proposed method includes pre-processing, feature extraction, feature selection, and finally classification. In this work, EEG signals were first decomposed into 5-s time windows and then decomposed into significant frequency sub-bands by TQWT. In the feature extraction step, a variety of linear and nonlinear features were extracted from all levels of TQWT conversion, per 5-s time window. Then, the AE method was used to reduce the dimensions of the feature matrix and the results showed that this technique has a very good performance as a feature reduction algorithm. In the last step, several classification algorithms were used, and it was observed that rbf SVM has better accuracy and performance compared to other classification algorithms. Experimental results showed that the proposed method has an accuracy of 99.42 for two-class problems and an accuracy of 99.53 for multi-class problems. One of the main advantages of the method presented in this article is its ease of implementation. Therefore, the proposed system has the ability to be used in future work as a non-invasive tool and to help individuals with epileptic seizures for faster diagnosis.

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Cognitive State Assessment

Augmented Reality Integrated Brain Computer Interface for Smart Home Control

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Abstract. Brain computer interface (BCI) technology is an alternate communication option for individuals with neuromuscular impairments. There are several challenges to optimal BCI use including positioning of the screen, ease of use, independence in access, and calibration. Our study is directed at the development of a practical, accessible, at-home use BCI system that addresses these obstacles. Our design utilizes an augmented reality (AR) head-mounted display as a solution to provide BCI stimuli and output. We used a battery-operated Bluetooth-connected 8-channel portable EEG system and a custom P300 selection matrix displaying icons corresponding to various home control actions. Finally, the BCI system is integrated with a built-in smart assistant (Google Assistant) which allows the user to control their environment. In this paper, we describe the engineering of this home-use BCI system designed specifically for people with Amyotrophic Lateral Sclerosis, a neuromuscular disease causing severe motor deficits and loss of mobility.

Keywords: Brain computer interface · ALS · Augmented reality · Neuromuscular disease · EEG · Assistive technology · AAC

1 Introduction

Brain Computer Interface (BCI) technology utilizes brain signals to output commands to devices for communication and environmental control [1]. This is significant, especially for providing disabled individuals an avenue of communication that requires no physical movement. BCIs commonly use electroencephalography (EEG) for acquiring brain signals at the scalp [1]. The system consists of the user attending to letters or icons that flash on a screen. Event-related brain potentials (ERPs) are detected by the computer that

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is able to recognize the user's selection [2]. BCIs can use different types of ERP signals including the P300 and steady-state visual evoked potential (SSVEP) [3]. Specifically, our focus is on P300-based BCIs. The P300 is a positive ERP occurring about 300 ms after a visual stimulus [2]. The oddball paradigm is characterized by a P300 in response to a target stimulus [2, 4].

Using the oddball paradigm, P300-based BCIs allow individuals with severe disabilities to make visual selections without the need for movement or speech [2]. Individuals with Amyotrophic Lateral Sclerosis (ALS) suffer motor-neuron degeneration causing the loss of voluntary movements [5]. When individuals can no longer communicate due to the inability to speak or move their extremities, augmentative and alternative communication (AAC) methods are needed to convey their needs. Additionally, BCIs can also give access to environmental control [6–8]. This involves control of devices such as lights, TV's, and smart outlets. Recent advancements in smart home technology such as Amazon Alexa and Google Assistant are making environmental control more accessible. Enabling individuals with ALS to control their environment would significantly increase their independence and quality of life [9].

BCIs have already been used as AAC for people with ALS. However, they require sustained and high levels of attention and cognitive load that can be fatiguing for users [10]. Additionally, long calibration times and complex set-up of traditional systems decrease the practicality of BCI for home use outside of a clinic setting [11]. Specifically, for individuals with ALS, the need to be upright and stare at a screen poses challenges. At any stage of the disease, neck weakness or dropped head syndrome can lead to the inability to hold the head up [12]. At later stages of the disease, individuals commonly find lying down or reclining most appropriate. Having to be propped up in an upright position can contribute to fatigue while using a BCI and deter individuals from using it. An ideal solution allows the user to utilize the system in any position.

Fig. 1. Our traditional BCI set-up with a computer monitor screen (left). Augmented Reality glasses worn with an EEG cap (center). Augmented Reality display (right)

In this study, we aimed to combine newer portable display technologies with P300 based EEG-BCI to address some of the problems arising from home use. Specifically, we have adapted the screen for stimuli and output projection via an augmented reality

(AR) glasses and utilized the BCI output for environmental control via Google Assistant. The use of AR glasses enables visualization in any position without the need for multiple recalibrations and adjustments of the user interface. Furthermore, AR glasses have advantages over virtual reality (VR) devices since the AR technology maps virtual objects onto the real world rather than a dark background or screen. Hence, the surrounding environment is still visible while wearing the glasses thereby reducing any sense of claustrophobia and allowing the user to see anything that is happening within the room. AR has become increasingly popular in medicine, as it allows for a unique way to display images [13]. A BCI in which targets are displayed on AR glasses could provide a solution to the problems of positional fatigue enabling use in any position (See Fig. 1). Finally, integrating BCI with smart home assistants like Google Assistant opens the door for future practical use scenarios.

2 Traditional System Set-up and Challenges

The current BCI system used at Temple Hospital's Department of Neurology clinic under Dr. Terry Heiman-Patterson, in collaboration with ALS Hope Foundation, consists of a 16-channel wet EEG electrode array and follows the standard 10–20 system of electrode placement [14]. The system uses a P300 classifier to train and test a linear classifier for detection of the evoked related potentials collected with BCI2000 [15]. A MATLAB GUI was designed for the analysis of the BCI2000 data collected using a speller [16]. The P300 Speller module implements a BCI that uses evoked responses to select items from a rectangular matrix [2]. This module can deliver visual and auditory stimuli in user-defined or pseudo-random sequences. In simulation mode, the simulated EEG will simulate evoked responses on the respective items, allowing to test signal classification and spelling functionality. Once calibrated, the purpose of the P300 Speller is to choose arbitrary letters from the matrix or even spatial navigation icons instead of letters for control of virtual environments [17].

Significant challenges have limited the home deployment of our traditional BCI system. First, the research-grade original systems developed are cumbersome to use, consisting of wet electrode caps, multiple wired connections to multiple components, the need for a large amplifier, and a display that consists of a computer screen that ran two different types of software. MATLAB software is utilized for weight calculation, C++ for the actual stimulus presentation and output display, and software that was written for decoding the signals. Also, having many sub-components render the system susceptible to failures and malfunctions. Furthermore, it would be hard to troubleshoot for the user in the home,

The second issue is the long set up time ranging from at least 20 min to 45 min or even more. This is a difficult time constraint for a busy caregiver and requires training in electrode placement and use of the programming reducing the quality of the user experience.

The system can also be uncomfortable for the user, requiring a fixed computer monitor screen to display the keyboard flashes that act as the visual stimulus for the ERPs. This leads to two major issues. First, the user needs to be in an upright position to keep the screen in their line of sight for best performance accuracy. This can be challenging to the user with ALS or other neuromuscular disorders due to fatigue and discomfort. Additionally, the calibration in these systems can add to the challenges. The screen is fixed w.r.t the user's head position. Given that individuals with ALS commonly experience cervical weakness, users will have difficulty maintaining head position for prolonged periods resulting in the likelihood that there will be a loss in screen calibration due to a shift in the neck position. Every recalibration adds 4–5 min to the set-up time before the system is up for use again [18].

Even when set up, with this system the process of communicating is time-consuming. It has been reported that on average a person speaks approximately 150 words per minute depending on individual, demographic, cultural, linguistic, psychological, and physiological factors [19]. This can roughly be equated to 500 characters per minute. A traditional BCI system can barely process 4–5 characters per minute in a practical test case [20]. This gap, between the characters that can be spoken versus processed by this system can end up being frustrating and time consuming.

Finally, the systems, as designed, has limited functionality especially based on the technologies now available. The traditional BCI system displays letters, numbers, and punctuations on the screen which may be used to spell out words and sentences. It is not interfaced to home control and there is a large dependence on a caregiver for set-up and to carry out a task that can easily be accomplished utilizing home control devices.

3 AR BCI Based Smart Home Set-up

3.1 Ultra-mobile EEG Headset

A significant drawback of the traditional system is the inconvenience of the EEG cap. It had 16 wet electrodes wired to a separate amplifier unit. This not only made putting on the EEG cap on the user an inexpedient task but also made it harder for the user to use the system lying down. Along with the hardware issues, the software used was very hard to run and set-up. These factors contributed to the interface not being home-use friendly.

We considered some basic points while choosing a new headset for our new BCI. Specifically, we opted for an ultra-mobile system that is battery-operated, wireless, and head-mounted. Before selection, we checked system specifications like sampling rate, battery life and type (e.g., rechargeable, or replaceable), how many EEG channels, electrode type (wet, dry, or both), usability (weight, wires, placement, configuration, and setup steps) After considering these hardware specific questions, we also took into consideration their respective software requirements. Does the headset come with its own software customization and extensions like software development kit (SDK) or application programming interface (API)? What is the developer community and available documentation for them? What are the different programming languages that the SDK/API is available in? How customizable is the SDK and can it be adapted to work with XR applications?

After considering these prerequisites, we decided to utilize Unicorn's Hybrid Black EEG Headset kit that has 8 EEG channels with electrodes that can be used either dry or with gel, a 24-bit sampling rate of 250 Hz and 6–8 h battery life, which can be recharged using any micro-USB plug. The electrodes are connected to a Bluetooth hub mounted on the back of the head that communicates with the computer using a Bluetooth dongle. The SDK is available in C, C#, and Python. It also has Lab Streaming Later (LSL) and User Datagram Protocol (UDP) data transmission capabilities which allow the SDK to be used with 3rd custom party applications as well.

3.2 AR Headset

One of the things that made the traditional system cumbersome to use was the fact that the visual input and output was using a flat LCD computer monitor panel. The user had to be in an upright position. Even change in placement of neck could cause loss of calibration, adding to the inefficiency.

We opted to eliminate this issue by replacing the LCD computer monitor with a head-mounted AR display goggle. Because the goggles are mounted on the user's head, they can be in any position they feel comfortable in; the screen displaying the inputs and outputs will always be at a constant location from their eyes. This eliminates both the issues of user fatigue and frequent loss of calibration.

We asked a lot of similar design questions while choosing an AR headset as well. Is the system built for commercial use and readily available? Was it wireless and had an inbuilt battery or was it wired to a computer and used that for power? How heavy is the whole headset? What is the field-of-view (FOV)? A small FOV would make the displayed image very small and centered on the goggles, making it harder to see. What is the refresh rate? We wanted a refresh rate of at least 30 Hz for our P300 speller display. If the refresh rate of the headset would have been lesser than 30 Hz, the user would have been able to notice each time the screen was redrawn, causing visual strain and fatigue. We also considered some software specific questions. Does the headset come with its own SDK/API? What are the different programming languages that the SDK/API is available in? Availability of the SDK documentation?

Finally, we selected commercially available DreamWorld's DreamGlass AR headset. It has a Unity based SDK that is able to run on Windows. It has a refresh rate of 60 Hz and 90° diagonal FOV. The AR headset is wired to a computer via HDMI cable and the AR display is recognized as an additional (second) screen on the computer (See Fig. 1, right). We utilized DreamWorld's AR Desktop app that mirrored the computer desktop onto an AR environment displayed on the goggles.

3.3 Raspberry Pi SoC

As we want the interface to be home-use friendly, portability was one of the biggest shortcomings of the traditional BCI system. The system was built for in-clinic research purposes. One of the main reasons for the low portability of the system was the high computing performance requirements of the traditional system. But, with the development of technology and the increase in the complexity and wide-spread availability of system-on-chip (SoC) computer systems, it has become possible to make portable architectures without a significant drop in computing performance.

The current AR BCI set-up works with 64-bit Windows 10 operating system and higher running on a quad-core chip with a clock speed in the range of 2.4 GHz to 3.8 GHz that can be overclocked to 4.1 GHz. The minimum memory requirement is 8 GB. The total graphics power of the hardware needs to have a base clock of 1150 MHz with a boost clock of 1340 MHz, a power consumption rating of 350 W, 2 GB of 128-bit DDR5 6.6 GBps memory with a core clock speed of 1024 MHz and 770 CUDA cores.

Although no single SoC currently available in the market met all those specifications, we decided to test a sub-system of the whole interface on a relatively low cost SoC to understand the feasibility of the task. Hence, we decided to go ahead with putting the smart assistant part of the system on the Raspberry Pi 3B+. It uses a Broadcom BCM2837B0 chip, with 64-bit ARM cores capable of running at 1.4 GHz and 32-bit VideoCore IV running at 400 MHz. These specifications were more than enough to support any smart assistant and its associated functionalities.

3.4 Smart Home Assistant

One of the limitations of the traditional BCI system, as mentioned above, was that the interface was built to be used only as a means of communication with the participant's health aide. Addressing this in our new system would reduce the dependance of the user on the caregiver for certain tasks, increasing independence. We resolved this issue by integrating smart home assistant in our interface giving user the capacity to control their environment. The interface was only tested with basic entertainment and device on/off actions, but with the vast possible capabilities of smart home assistants, the applications are endless.

Both Amazon Alexa and Google's Google Assistant can be set up in a relatively low-cost SoC like Raspberry Pi (we used 3B+). However, only Google provided the developers with documentation to modify the code to work with other triggers as like a physical button press, a software call etc. This allowed us to finally integrate the Assistant in our BCI interface which in-turn gave the user access to all of the Assistant's functions.

3.5 Overall System Design

In the preceding section, we have explained the changes that have been implemented in the hardware and software in order to develop a more effective and robust BCI system. The overall proof-of-concept BCI block diagram is depicted in Fig. 2.

The EEG cap is placed on the user's head with the 8 electrodes placed at FZ, C3, CZ, C4, PZ, PO7, OZ, and PO8 following the Unicorn's default 10–20 system of arrangement. The electrodes are wired to a Bluetooth module placed on the back of the head that communicates with the computer via bluetooth and sends the signals for further processing. The AR headset is placed on the user on top of the EEG cap to act as the stimulus display (the modified speller interface) and the output selection. The signals sent to the computer are processed in the Speller software. Once the required selection is made, the associated function call is made to the Google Assistant listening for it on the Raspberry Pi SoC. Once the assistant receives the input, it processes the input, sends the instructions to Google Cloud Services which then executes the corresponding action.

The new BCI system developed by our team is designed to provide improved access with a broader range of capabilities as compared to the original design. There are certainly additional improvements to be implemented as we will be performing a human test of our system with healthy volunteers. The new system is expected to provide ease of use with

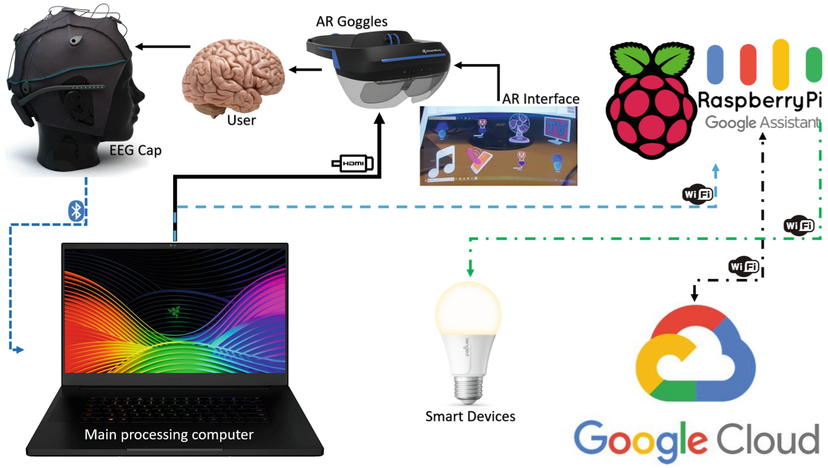

Fig. 2. Our new AR integrated P300 based home BCI system architecture

speller-based selection. However, increasing the speed of selection, and hence reducing the time of each icon selection remains one of the factors that can be improved upon in the future versions.

AR technology is also constantly evolving and expanding with rapidly improving hardware and software, as it is still in early phases of its development cycle and consumer adaption. Going forward, we look to improve the AR experience with better headsets and software. We are also hoping to reduce the size and portability of the overall BCI system.

As embedded computation units improve, we further expect that computational performance will increase, and hardware's power consumption will decrease, enabling integration of all the processing into a single powerful SBC to make the overall BCI system more portable, streamlined, and easier to manage.

Future studies could also explore other BCI paradigms and other fields of application for interaction in augmented reality environments.

4 Conclusion

In this paper we explained a new proof-of-concept AR based EEG-BCI system targeting home use for people with ALS. This paper outlined the design of this initial protype, and the challenges faced, lessons learned during its development along with future directions. As BCI research and consumer electronics industry rapidly evolve, new opportunities emerge for developing enhanced minimally intrusive and non-invasive BCI systems.

Overall, we have proposed a scalable approach to guide the design of BCIs using AR. We believe that AR is a promising new medium that could be adapted and reused in other BCI types and could orient future research on BCI-based interactions in mixed reality.

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Expectations in Human-Robot Interaction

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Abstract. It is acknowledged that humans expect social robots to interact in a similar way as in human-human interaction. To create successful interactions between humans and social robots, it is envisioned that the social robot should be viewed as an interaction partner rather than an inanimate thing. This implies that the robot should act autonomously, being able to 'perceive' and 'anticipate' the human's actions as well as its own actions 'here and now'. Two crucial aspects that affect the quality of social human-robot interaction is the social robot's physical embodiment and its performed behaviors. In any interaction, before, during or after, there are certain expectations of what the social robot is capable of. The role of expectations is a key research topic in the field of Human-Robot Interaction (HRI); if a social robot does not meet the expectations during interaction, the human (user) may shift from viewing the robot as an interaction partner to an inanimate thing. The aim of this work is to unravel the role and relevance of humans' expectations of social robots and why it is important area of study in HRI research. Moreover, I argue that the field of HRI can greatly benefit from incorporating approaches and methods from the field of User Experience (UX) in its efforts to gain a deeper understanding of human users' expectations of social robots and making sure that the matching of these expectations and reality is better aligned.

Keywords: User experience · Human-robot interaction · Expectations

1 Introduction

The field of Human-Robot Interaction (HRI) has emerged, in part, to gain a deeper understanding of how humans interact 'naturally' with social robots [1]. Social robots are physical artifacts that are created for the purpose of behaving as an interaction partner [2]. Social robots should be able to (1) interact with its user, (2) serve different functions, and (3) possess social skills [5]. Its embodiment in the world, as well as its engagement with the world, are key components when defining socially interactive robots [3]. Social robots can therefore be created for the sole purpose of being companions, partners, and assistants to humans, while being implemented in applications areas such as hospitals, health care, education, and entertainment. Subsequently, there is a need to investigate and analyze what kinds of expectations humans have of social robots and how these expectations influence the interaction quality.

It is not an easy task to answer why some robots trigger social responses from humans, but there has been great progress to deepen this understanding. For example,

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the study of anthropomorphism addresses how a robot with human physical features, e.g., eyes and mouth, allows for expectations of behavior similar to a human being [2]. In fact, anthropomorphism is specifically used as a mechanism to evoke expectations of social competence. Expectations, thus, play a crucial role in HRI as they set the tone for the interaction quality. Humans tend to attribute mind, or agency, in other humans, animals, and artifacts [4, 5]. It has been shown that robots do not need to have the same level of intelligence as humans to be perceived as intelligent [2, 6]. The field of HRI aims to understand and develop social robots that take advantage of this tendency. It is therefore important to understand what the main goal of the robot is. If this is not considered, skewed expectations might occur which can lead to seeing the robot as an inanimate object.

While the general goal for HRI designers is to create robots that interact with humans, the toolbox and methodologies to reach this goal differ [1]. The User Experience (UX) field aims to analyze, design, evaluate, and implement artifacts with the user's experience in mind [7]. From a UX perspective, a social robot is rather seen as a tool to achieve a certain goal in a certain context of use. The goal, therefore, defines what the role of the social robot should be and what kind of tasks it should carry out to achieve that goal based on its end-users and the particular usage context. On the one hand, if the aim of a robot is to serve as a companion for older adults with the goal for these users to experience being less alone; the robot should, in the best of worlds, fulfill some identified social needs and would be expected to exhibit social behaviors. On the other hand, if the aim of a robot is to vacuum floors in a home with the goal for the users to experience less stress over cleaning, it would not be expected to behave socially to the same extent as a robot that is supposed to aid in feeling less alone.

In this work, I will discuss why humans' *expectations* of social robots play a crucial role in the user experience of social robots. Applying UX methodology [7] provides a viable approach to systematically develop and evaluate/assess/study expectations in order to create social robots with a positive UX. This is of importance as expectations of social robots may function as a confounding variable that threatens the internal validity of any HRI research.

2 Expectations

Expectations can be defined as believed probabilities of future events that sets the stage for the human belief system, which guides our behavior, hopes, and intentions [8, 9]. Humans can vividly conjure images of possible outcomes, even if the situation has not yet occurred, allowing regulation of behavior [9]. In real-time interactions with other beings, expectations serve to orchestrate anticipations of possible actions. As expectations are predictions of the future, expectations are often aligned with wishful thinking, and consequently can result in disappointment [8]. When an expectation turns out to be correct, it is confirmed, whereas when an expectation turns out to be false, it is disconfirmed. A constant pattern matching is unfolding between previous outcome, expected outcome, and actual outcome; sometimes called fluency processing [8]. This process of expectations analysis is mostly carried out implicitly and happens swiftly with low cognitive effort. It is acknowledged that once expectations are set on a specific outcome, they are difficult to disrupt [9]. Therefore, it is important to understand how expectations affect UX before, during, and after interaction with social robots. Expectations are studied in the field of UX as it is an important aspect of user experience [10]. If an interaction with an artifact does not meet expectations, a user can experience negative UX which affects the user's emotions as well as the acceptance of the artifact [7].

2.1 Expectations of Social Robots

Social robots have not yet fully emerged in society and most people lack first-hand experience and technical knowledge of these artifacts. Most humans rely on expectations based on what they have seen in the media and it is therefore hard to foresee what kind of expectations humans have of social robots [11]. An obvious source of exposure of robots in media is science fiction. Movies like 'Ex Machina' and shows like 'Westworld' portray robots as super humans with a very high degree of artificial intelligence. Although these examples are obviously not real, they still constitute a significant basis for people's exposure to social robots.

Perhaps more noteworthy is what kinds of expectations exist for real social robots. For example, a study by Billing et al. [12], found that assistant nurses had unrealistic expectations of what social robots will be able to perform in welfare, both now and within 10 years. Moreover, part of the FP7 project DREAM carried out by my research group, the effects of robot-enhanced therapy for children with autism spectrum disorders was studied [13]. This study was made with a clinical protocol where written consent was obtained from caregivers to the participating children. Still, both children and their parents arrived with certain expectations, possibly very different from the experience of interacting with a real robot. These expectations do affect the study itself, especially in situations where we are interested in users' attitudes towards robots. After reading about the DREAM project in a newspaper, a parent to a disabled child, not involved in the study, contacted us with the hope of being able to purchase such a robot for her child. While the engagement of the public is of course very positive, the parent had in this case clearly formed unrealistic expectations of the robot's cognitive and social abilities, assuming that such a robot is able to function as a social companion on an everyday basis.

Designing robots with social cues, e.g., eyes, mouth, and nose, is in its nature deceptive as the robots are not able to utilize these features like humans while users will infer that this is the case [11]. Deception is also a common tactic in HRI studies as it allows for insight into human behavior. Wizard-of-Oz (WoZ) is a popular technique where the robot is remotely controlled by a human, making it appear as if the robot is able to behave in certain ways that is not possible today [14]. If participants are not made aware of this deception, expectations of future interactions with robots might be affected by these deceptive experiences.

Moreover, it is not uncommon to advertise social robots as companions with human feelings, thoughts, and empathy, showing robots that do not exist yet. Artifacts are often sold with unrealistic advertisements, like a car that transforms into a robot that dances; however, although commercials for social robots and cars have many similarities from a marketing point of view, I stress an important difference in that cars are commonly known to the customers and the expectations are based on previous exposure to them.

That is, it is apparent for customers' what part of the car is real and what is not. The same line of argument does not hold for social robots; they are not yet a part of our daily lives and the expectations are not built on first-hand experience. Therefore, negative UX can occur in HRI which may result in the robot not being used altogether [11].

3 Studying Expectations with UX Methodology

In recent years, there has been an increased interest in incorporating UX methodology in HRI research [15–17]. People have higher expectations on social robots than most other artifacts studied in UX [15, 18]. Hassenzahl and Tractinsky [10] stress three main factors that make up UX; (1) the internal states of the user (2) the designed systems characteristics, such as its purpose, complexity, and usability; and (3) the context/environment for the interaction. Being aware of these factors allows designing for a positive UX. These main factors can be applied in HRI research; for example, user's expectations (internal state) of a social robot (designed system characteristic) in an assisted living facility (context).

The UX design lifecycle, or UX wheel, is a model of core activities in UX [7]. The wheel consists of four iterative steps: *Analyze, Design, Prototype,* and *Evaluate*. The main purpose of the UX wheel is to ensure that the goal of any artifact in its context is fulfilled. The UX wheel provides support to systematically study how user expectations have an impact on the experience of social robots – before, during, and after the interaction. Below, each step of the UX wheel is presented along with an example of how it can be applied in HRI, drawing inspiration from the example mentioned in the previous paragraph.

3.1 Analyze: Understanding User Work and Needs

This step refers to when field data is elicited and analyzed through interviews and observations by studying users' work practices or daily habits [7]. The overall aim is to identify and formulate the needs of the end-users and gain an understanding of the bigger picture. This step is beneficial for HRI as it can help us understand the context in which the robot will operate and what expectations users will have of the interaction. If, for example, a robot is designed to be a companion at an assisted living facility, the users are the older adults living in that home. First steps would include understanding what aspects of companionship the robot should fulfill, including users' expectations of the robot, and the context it will operate in. If the goal is to have an effect on the user's well-being, we can start by studying what the user's might need in their everyday life and what they expect from the interaction. The user might feel lonely and forget to take medication. Perhaps the robot should be able to interact with as many user as possible.

3.2 Design: Creating Design Concepts

This step refers to when the gathered information is realized in UX goals and conceptual design concepts to actualize the user's needs and expectations [7]. When designing for emotional needs, the designer aims to make the design meaningful. If the analysis of the gathered data reveals that the users are feeling lonely, robot features could include face-tracking, communication abilities, and having a fuzzy exterior. All of which could possibly fulfill the need to feeling less lonely. From this, it could be deduced that the users would benefit from interacting with a social robot (viewed as an interaction partner) to fulfill these needs. Therefore, the social robot should be designed with this in mind. If the social robot is expected to go between rooms to talk to several users, having wheels could be beneficial in order to reach the different users. If it is revealed that the users expect that the robot will be able to hug, features could be implemented in order to meet these expectations. If, however, it is not feasible to implement such changes, changing the design to lower expectations could be an option. Perhaps a robot with immobile arms, showing clearly it cannot lift its arms for a hug, or designing the social robot as a zoomorphic animal, thus lowering the expectation of communicative skills but still being able to fulfill other social needs, such as having a soft fur to pet.

3.3 Prototype: Realizing Design Alternatives

This step refers to when different kinds of prototypes are created from conceptual designs in order to evaluate an artifact before committing to the final design [7]. This is beneficial as changing the artifact after it's created can be costly and time consuming. Prototypes can be useful in HRI as it can help manage expectations by investigating what features fulfill the user needs. For example, if we want the social robot to appear talkative as a way to invite interaction, different low-fi prototype options could be presented in order to assure aligned expectations and reality. This could include comparing an anthropomorphic robot and a zoomorphic robot to have the possibility to investigate which design option is the most suitable for the identified needs and formulated UX goals. However, it can be hard to create functional hi-fi prototypes as social robots are usually complex and need to be completed before it can be properly used [19]. There are ways to go around this; for example, a WoZ set-up allows for testing some aspects of the robot while it is still not implemented.

If we go back to the social robot in an assisted living facility, we could study what kind of expectations the user has before, during, and after the interaction by having the user interact with a prototype. The users could expect that the social robot would respond to being touched, and experienced disappointment when this did not occur. More prototype testing could therefore include the robot, still being remotely controlled by the designer, giving auditory feedback to being touched without having to actually spend time programming this feature. If it has a positive outcome, implementing this feature would be deemed worth the resources.

3.4 Evaluate: Verifying and Refining Designs

This step refers to when the work is evaluated with various methods to assess how well the artifact fulfills its goal. The goal is to identify and improve UX problems (e.g. design flaws). There are two major approaches to UX evaluation; formative and summative evaluations [9]. Formative evaluation occurs during the development process and a summative evaluation occurs on the final social robot. The purpose of formative evaluation is to receive feedback on design ideas in the earlier steps in the UX wheel, e.g., via sketches of interaction flow or physical mock-ups of the envisioned robot. Summative evaluation is used to measure the UX of a high-fidelity prototype or the final artifact. It could also be used to gain an understanding of its usage in practice, i.e., in an ecologically valid environment [16].

This step evaluates how well the social robot is fulfilling its goals and to what extent user expectations are met. If there are still severe UX problems left and major expectations are not met, the UX designer will perform another iteration in the UX wheel and continue until UX goals and expectations are met. By a sequence of formative and summative evaluations it can be determined what needs to be refined with the social robot in the assisted living facility. For example, if the social robot does not meet the expectations of being socially competent despite previous steps, the designer can go back and refine the issue by updating certain features like designing the robot to ask the user to repeat themselves when the question or command is not understood by the robot. By summative evaluation, it is determined whether all the UX goals are fulfilled and the social robot is meeting the expectations of being a companion and has improved the well-being of the users living in the assisted living facility.

4 Conclusions

Expectations could be a severe confounding variable that ought to be considered in any HRI research as exposure to social robots are rare and assumptions are made mostly from media; ultimately threatening the internal validity [11]. If disconfirmed expectations of social robots cause negative UX, there is a need to discuss how to prevent it.

Expectations can be combated by, for example, revealing the actual capabilities of the social robot to people, e.g., showing the mechanical parts that make up the robot in order to grasp its lifeless nature [11]. A study by Sun and Sundar [20] found that participants had a more positive experience with robots when they assembled the robot themselves, demonstrating that a good interaction can still occur even if they participants knows what is ‘under the hood’.

What I argue for in this paper is to include UX methodology when designing and evaluating social robots. Being able to assess expectations at an early stage, following the UX design lifecycle, is crucial if we want to study and evaluate how users are experiencing social robots. However, employing the UX design lifecycle is not always feasible since some of the social robots that are being used in HRI today are often bought from robotics companies and are rarely self-built in the lab. There is therefore very little a HRI researcher can do in terms of designing them from scratch, as the UX design lifecycle promotes. Bringing in UX after the fact has traditionally little use after the design process [7].

Moreover, HRI research comprise also many technical topics of social robots, far from a specific UX design. Still, I believe that incorporating some aspects from UX design could be useful in any stage of HRI, to help researchers gain a deeper understanding of how well a robot suits a particular context of use. Although many robots are bought ready-to use, it is still possible to design some robot behaviors, such as social behaviors that are suitable for a specific context. For a social robot situated in an assisted living facility, adding features like asking if the user has taken their medicine, or having conversations, can still be added to most social robots. Similar efforts have been made by Tonkin et al. [17], proposing a UX methodology in robotic applications for commercially available social robots.

In addition, as people seem to have solid views of robots and expectations are hard to disrupt, it might be a challenge to adjust/change these expectations. It is therefore of major importance to study whether and to what extent expectations can be changed over time – before, during, and after interaction. According to Manzi et al. [3], expectations of the mechanical properties of a robot are higher before an interaction with a robot. Edwards et al. [20], showed that, not only do participants have expectations of interactions, but that this can also change after exposure to robots. After the interaction, participants demonstrated less uncertainty and greater social presence.

From an ethical point of view, though there are many kinds of social robots, there are even more kinds of humans. Not all humans fit the'norm' and some might benefit from social robots because of it. This is especially important in health care as there will be patients with specific needs that fall outside the norm. A UX designer has a responsibility to make sure that the design of a social robot is ethically justified which might sometimes go against other needs such as stakeholders [22].

Indeed, UX methodology can be beneficial to predict and prevent disconfirmed expectations in robots; whether if it's to view them as a thing or as an interaction partner. In the field of HRI, it can be assumed that the underlying goal of an interaction is for the human to expect to interact with an interaction partner. From the vast HRI literature, it is evident that this is indeed possible. Nonetheless, each interaction is unique and some social robots are able to trigger a higher level of expectations than others. According to Alač [6], some components of social robots evoke life-like expectations, such as mirroring head movements, whereas other components don't, such as a touch screen designs on the robot. Users can therefore expect and view a social robot as an interaction partner, while handling the robot as a thing. As Alač eloquently put it, "The robot is a special thing because of its agential characteristics" [6, p. 533]. There are many dimensions to expectations and more research is needed in order to gain a deeper understanding of how it affects HRI research. UX methodology, including the UX design lifecycle, could be a useful tool to reach this goal.

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Application of Recurrent Convolutional Neural Networks for Mental Workload Assessment Using Functional Near-Infrared Spectroscopy

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Abstract. Mental workload assessment is a core element of designing complex high-precision human machine interfaces with industrial and medical applications, from aviation to robotic neurosurgery. High accuracy and continuous mental state decoding play an essential role for keeping the operator's mental workload on a moderate level to prevent cognitive tunneling and improve the safety and performance of complex machine use. Monitoring brain activity using wearable and increasingly portable functional near-infrared spectroscopy (fNIRS) sensors enable measurement in realistic and real-world conditions. While a variety of machine learning techniques have been evaluated for this application, Recurrent Convolutional Neural Networks (R-CNN) have received only minimal attention. A significant advantage of R-CNN compared to other classification methods is that it can capture temporal and spatial patterns of brain activity simultaneously without requiring prior feature selection or computationally demanding preprocessing or denoising. This study represents an investigation on designing a hybrid deep learning architecture combining CNN and RNN (Long Short Term Memory-LSTM). The proposed architecture is evaluated for mental workload memory (n-Back) tasks from an open-source dataset. Proposed architecture demonstrates higher performance than both Fully Connected Deep Neural Network and Support Vector Machine methods, showing a high capacity for simultaneous spatio-temporal pattern recognition. We obtained improvements of 15% and 11% in average subject accuracy with deoxy-hemoglobin (deoxy-Hb) in R-CNN compared to SVM and DNN methods, respectively.

1 Introduction

Application of machine learning methods for the classification of cognitive events recorded by functional Near-Infrared Spectroscopy (fNIRS) has been the focus of many

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research studies in recent years. These methods have been employed extensively in Brain Computer Interface (BCI) and Human Machine Interface (HMI) applications with industrial and clinical applications, such as in aerospace and robotic neurosurgery. Support Vector Machines (SVM) and neural networks are the most commonly used methods for classification of mental workload and arithmetic tasks [1, 2], as well as motor imagery tasks [3, 4]. Such Machine Learning (ML) methods usually need a priori feature selection and preprocessing which is not always guaranteed to result in optimum classification. The result depends on factors such as selecting the best set of combined features [5]. With recent advances in computational capacity, deep learning methods such as Convolutional Neural Networks (CNN) and Recurrent Neural Networks (RNN) are considered attractive alternatives to avoid challenges faced by conventional methods. An RNN is a generalized version of a feed-forward neural network that has an internal memory, which provides the possibility of leveraging past events in pattern recognition. Many studies have discussed the employment of CNN or RNN for neuronal signals [5–10], but only a few studies have addressed the application of them for fNIRS [5, 9, 11, 14, and 15]. On the use of CNN for fNIRS, Trakoolwilaiwan et al. [5] and Saadati et al. [9] used CNN structures for classification of a three-class motor execution (6% improvement in accuracy compared to SVM) and mental workload memory task (8% improvement in accuracy relative to SVM), respectively.

RNN and specifically Long Short-Term Memory (LSTM - an advanced type of RNN) structures, when combined with CNNs, are capable of decoding using spatio-temporal representations. Using fusion of Recurrent Neural Networks and Convolutional Neural Networks (R-CNN), we leverage their end-to-end learning ability directly from the raw data rather than from a set of established prior features. We have previously investigated temporal pattern recognition in fNIRS using Convolutional Neural Networks [11]. When temporal methods are used, the possibility of overfitting and omitting the spatial pattern of the signals limits the performance of the classifier [11]. This study provides a R-CNN classifier for simultaneous spatio-temporal pattern recognition in the neuronal signals that improves upon the performance of the classifier considered in the previous studies.

The proposed network is trained and tested with temporal sequences of spatial images from fNIRS mental workload memory (N-back) paradigm to evoke mental workload Results are compared to three methods: SVM, DNN and a CNN with temporal images. Performance evaluation makes use of an open-source meta-dataset (including 26 healthy participants) collected at the Technische Universität Berlin by Jaeyoung Shin et al. in 2017 [12, 13]).

The remainder of the paper is structured as follows. A description of network development is provided in Sect. 2, and its implementation is described in Sect. 3. Section 4 concludes the paper.

2 Network Development

To pursue the objectives of the research, two aspects of DL classifier design need to be addressed: **data representation and network architectures**. Designing the data representation approach is critical to the classification problem since the time-series data must be converted to image format to take advantage of the CNN and capture the largest correlation between recordings in the classification process. In this paper, employing our previously developed temporal image representation methods [11], we focus on R-CNN architecture development to preserve the largest amount of classification-relevant content in the data and simultaneous spatio-temporal pattern recognition.

2.1 Brief Overview of Network Components

CNN. A CNN is constructed from a combination of convolutional layers, pooling, and dropout layers. In a convolutional layer, a 2D filter is convolved with the input images to produce activation maps, which are updated in each layer. A nonlinear activation function is applied to these feature maps to build the activation maps, afterwards. This activation function defines a nonlinear decision boundary for the output of the convolutional layer which allows the network to learn complicated features from previous layers. Then, the optimizer minimizes the loss function using gradient descent method and calculates the corresponding weights in the layer [11].

LSTM. LSTM can be viewed as a neural network that includes "memory" feedback from previous samples in the neurons, a characteristic that is very beneficial when working with sequential data [14]. LSTM has been used extensively and successfully in time-series prediction and natural language processing [16, 17]. The flow of information in LSTM is based on three gates: input, output, and forget gates, as depicted in Fig. 1. The outputs of each block of the LSTM are current and hidden signals, referring to the states of the current block and updated weights from all of the previous blocks, respectively, controlled by the aforementioned gates. These signals are used in updating the weights in the next LSTM cell.

Fully Connected Layer (FC). After convolutional layers, a fully connected layer (FC) is added to flatten the weight matrices into weight vectors. These vectors are fed into the LSTM block, or any other layers depending on the architectures. Finally a softmax layer calculates the probability of each class for the samples and classifies them.

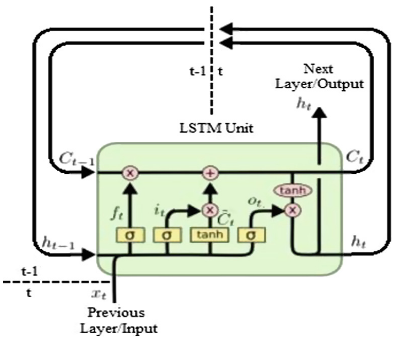

Fig. 1. An LSTM block includes three gates: Input, output and forget gates. It updates the weights of a neuron based on the state of the previous hidden layer (Figure from http://colah.github.io/posts/2015-08-Understanding-LSTMs).

2.2 Network Architectures

The R-CNN classifier is built using a combination of a CNN and LSTM. A CNN with three convolutional layers (including max-pooling and dropout layers after each convolutional layer) is combined with LSTM in a serial fashion.

The proposed R-CNN classifier uses continuous time sequences of spatial images as input to achieve the ability of simultaneous spatio-temporal pattern recognition in brain signals. Spatial images are formed based on interpolation between optod measurements on the brain map. Using spatial image construction, the number of images increases remarkably relative to temporal image formation, and training is greatly improved. Also, using two dimensional convolutions and spatial correlation between pixels allows us to extract valuable spatial features and leverage them in classification.

In this architecture, a CNN with three layers is cascaded with an LSTM using a fully connected layer with 128 neurons. The number and size of the filters in the CNN in all of these architectures are 32 and 3×3, respectively. The output layer consists of three units (depending on the number of classes) with a soft-max activation. Figure 3 depicts the network architecture. The length of each continuous time sequence input covers a 3-s time window of the signal, using a sequence of spatial images.

3 Implementation

3.1 Dataset and Preprocessing

An N-Back task dataset collected at the Technische Universitat Berlin by Jaeyoung Shin et al. [12, 13] is used to examine the performance of the proposed algorithm. The dataset includes simultaneous fNIRS (36 channels) recordings of the scalp for mental workload during n-back (0-, 2- and 3-back) tasks. These tasks are classified into one of three classes: 0-, 2- and 3-back tasks, relative to rest. The study included twenty-six right-handed healthy participants. The details can be found in [12]. Figure 2 depicts the pipeline of classification. For preprocessing, the Deoxy- and Oxy-hemoglobin signals, HbR and HbO, are low-pass filtered with a cut-off frequency of 0.08 Hz using a second-order digital Butterworth filter to remove physiological noise. To calculate the biomarkers relative to rest, (calculating ΔHbO and ΔHbR), baseline correction was applied [9]. The calculated values are used to build images that are fed to the CNN, as shown in Fig. 2.

3.2 Evaluation

The R-CNN classifier performance is compared to SVM (Gaussian), DNN, and CNN. The DNN, shown at the bottom of Fig. 2, consists of 4 hidden layers. The number of neurons is 128 for each hidden layer independent of the number of channels. The number of the neurons in the input layer is the summation of the *HbO* and *HbR*. The CNN has three convolutional layers and two fully connected layers (including max-pooling and dropout). The number of the neurons in the two fully connected layers are 512 and 128, respectively. The output layer consists of three units with a soft-max activation. Thirty-two kernels of size 3×3 are used in each layer.

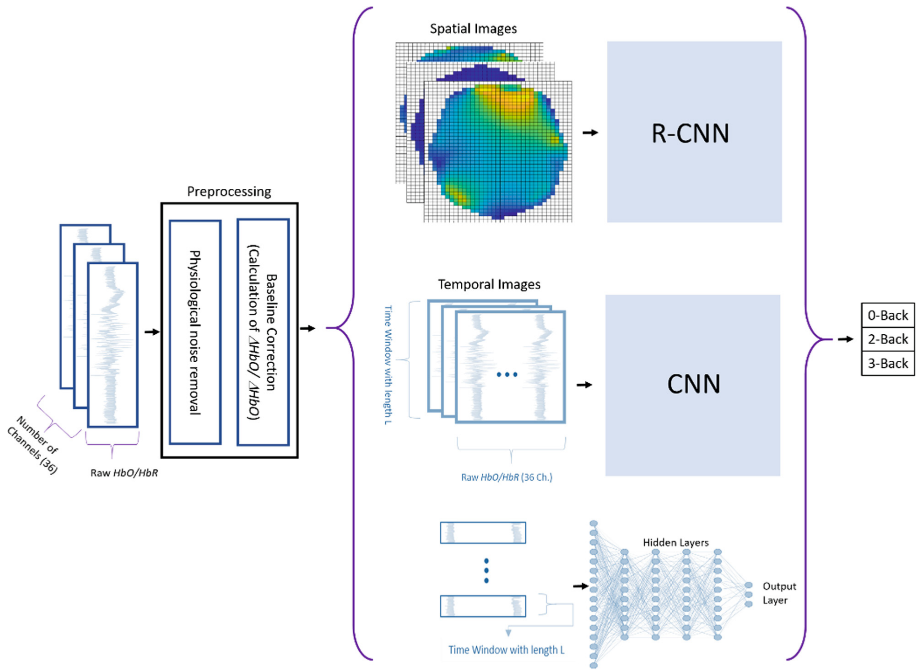

Fig. 2. Flow of the classification; HbR and HbO, are low-pass filtered, baseline corrected and used to build the input images. Then images are fed into the classifier.

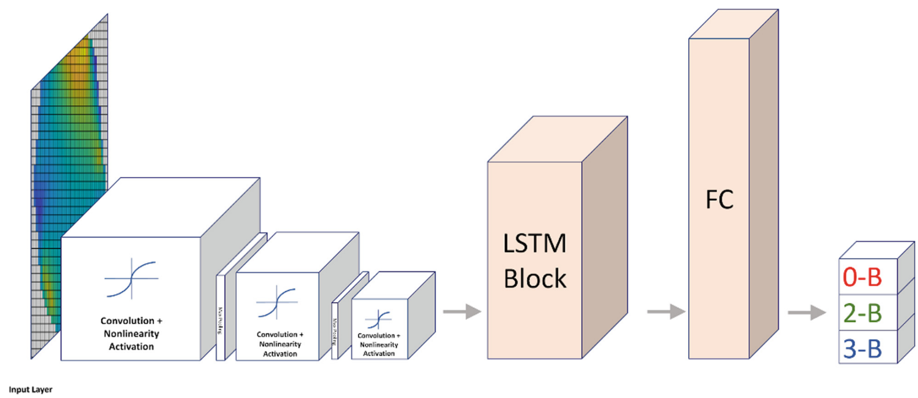

Fig. 3. In the R-CNN architecture, LSTM blocks are added after the convolutional network.

The average subject accuracy and standard deviation of all of the classifiers applied on both datasets are shown in Fig. 4. The average improvement of the average subject accuracy (compared to SVM as the baseline method) is summarized in Table 1.

R-CNN reaches the highest accuracy of 98.3% with roughly 10%, 11%, and 15% improvement compared to the SVM, DNN, and CNN, respectively. Also, the standard deviation of the R-CNN is negligible compared to the DNN, CNN and Temporal CNN, yielding reliable classification.

Table 1. fNIRS average intra-subject accuracies for N-Back experiments.

Network type	N-Back decoding accuracy
SVM	83.1
DNN	87.1
CNN	88.7
R-CNN	98.3

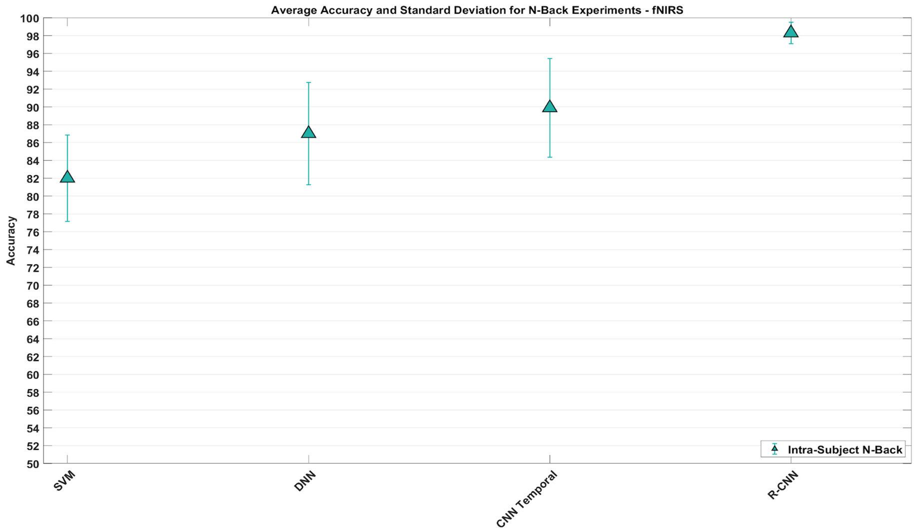

Fig. 4. Top: Intra-subject average accuracy and standard deviation score of the classifiers applied on N-Back dataset.

4 Conclusion

An R-CNN classifier is developed and evaluated for mental workload assessment. The architecture demonstrated higher performance than DNN, Support Vector Machines, and CNN as the baseline methods. We obtained a significant performance improvement in the intra-subject experiment using *HbR*, (15%, 11% and 10%) compared to SVM, DNN, and spatial CNN, respectively. Considering the results, this architecture is recommended for intra-subject classification. The methods are general and can be used in any type of cognitive and neuro-ergonomic task classification using fNIRs measurements.

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Influence of Properties of the Nervous System on Cognitive Abilities

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Abstract. The data analysis has demonstrated that the general intellect (IQ) has the high relationship with strength and functional mobility of nervous processes, if those indices have been strengthened indices proposed by authors (namely, accounting noise immunity indicators, as well as the verbal and nonverbal intellect) in the 1st group of subjects. Thinking ability had the higher relationship (R = 0.80, p < 0.01). At the same time, students-researchers (military psychophysiologists should be researchers) demonstrated much more close dependence in those indices: the general intellect had extremely high relationship with extended FMNP indices (R = 0.82, p < 0.01), and thinking ability even higher (R = 0.95, p < 0.001). The possible reasons and ways of application are discussed.

Keywords: Cognitive activity · Physiological support · External factors

1 Introduction

Though Industry 4.0 is still at a nascent and discussed phase, it is clear that technology will play a central role in nearly all aspects of our lives [1], and digital transformation is the most valuable trend and challenge, especially under effect of the Pandemic [2]. Digitalization of all human fields of activity has led to the emergence of new professions that needed high intellectual and creative abilities ensuring the high human professional performance [3]. Ability and readiness to learning and research activity became an important challenge to workforce capabilities [4] to meet requirements of the job market [5].

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At present, cognitive abilities predetermine the value of a person, both as a student and as an employee, and the talent hunting and talent management are important tools at the workforce market [6]. Measurement of the intelligent and emotional quotients are used very often, however not only the intellect, but also thinking ability and appropriate personality traits are needed for many professions [7].

Purpose. Analysis of relationship between intellect components, mindfulness, personality traits and features of the nervous system of experienced specialists and master students in occupations related to the cognitive work.

2 Method

The methodological basis of our research is a computerized technique based on models and methods for assessment of human abilities to cognitive work using intellectual and personality structures' indices for professional selection [8]. Tests were used as follows: modified R. Amthauer test of intellect structure; original and extended Hilchenko-Makarenko technique to measure strength (SN) and functional mobility (FMNP) of nervous processes; Myers-Briggs Type Indicator (MBTI).

The *tests* included:

Myers-Briggs Typology Indicator (MBTI); the purpose of use - an assessment of the ability to certain activities and individual properties of communication; Traditional indexes of an individual typology estimation according to the Myers-Briggs methodology are recorded based on the evaluation of the prevailing signs on the 4 criterion scales: extraversion E - introversion I (orientation of consciousness), intuition N - sensory S (way of orientation in a situation), thought/judgment J - perception P (method of preparation of decisions), thinking T - experience F (decision-making);

Modified Intellectual Structure Test for R. Amthauer (TCI); purpose of application - definition of the level of development and structural features of intelligence, as well as attention, memory; The following subtests are used (the brackets show the corresponding structural component of the intelligence): LS (testing of language, ability to formulate judgments), GE (conceptual intuitive thinking), AN (combinatorial abilities, mobility and ability to switch thinking), RA (ability to solve practical computational problems character), ZR (logical and mathematical thinking), FS (figurative synthesis), WU (spatial thinking), ME (memory, attention). The values of the structural components of intelligence were calculated as the sum of the correct answers for each subtest, the values of verbal (VI) and nonverbal (NI) intelligence - as sum of values, respectively, LS, GE, AN, ME and RA, ZR, FS, WU. The overall IQ score was calculated as the sum of values VI and NI with a correction factor of 1.462.

Hilchenko-Makarenko technique to measure strength (SN) and functional mobility (FMNP) of nervous processes. Individual-typological properties of higher nervous activity, due to the speed and mobility of nervous processes, are calculated [9].

The development was carried out in two main directions: first, the use of two consecutive 3-minute periods - without interference and with interference (in the form of color spots that appear randomly on the display screen, with simultaneous supply of sound signals of different modality); secondly, calculation not only of the minimum and final reaction time, but also calculation of additional characteristics of dynamics of performance of the test; thirdly, determination of human interference immunity by calculating the ratio of the values of the same indicators when performing the test with and without interferences.

The following indicators were calculated (further in research and discussion they are marked with index "10"):

minT - the minimum time of presentation of the task, corresponds to the maximum rate of work of the person, his maximum working capacity; maximum work pace.

maxT - the maximum time of presentation of the task, at high productivity, as a rule maxT = To; minimum work pace.

To - the starting time of presentation of the task; starting work pace.

tmin - time to reach minT from the beginning of the test; time to reach maximum pace.

S - the speed of reaching minT, depends on both the individual and typological characteristics of man, the lability of his nervous system, and the ability to mobilize.

Tcp - the average work pace.

DminT = |minT – Tcp|, mobilization reserve.

DmaxT = maxT – Tcp, mobilization lost.

There were measured the same indicators when working with hindrances (marked with index "11"). Indicators of the interference immunity (as the ratio of the corresponding indicator of test 11 and test 10) were calculated: f_1 = Tcp11/Tcp10 - average interference immunity, f_2 = tmin11/tmin10 - interference immunity when reaching maximum performance's rate, f_3 = S11/S10 – interference immunity of the speed, and f_4 = minT11/minT10 - interference immunity at maximum performance.

The resulting primary data was entered into a spreadsheet for further analysis.

Subjects. 56 subjects participated in the research: 28 experienced medical care professionals (18–40 years old) and 28 Masters in Psychophysiology (Bachelor of Medicine, 21–23 years old).

3 Results and Discussion

As it has been demonstrated in our previous research, the relationship between physiological indices of adolescent and external factors (solar wind and atmospheric parameters) was medium, but significant [10].

Besides, the analysis of combined influence of the external factors (solar wind speed and density of its proton component at the time of test performance) and physiological maintenance has revealed their parameters' high correlation with tests performance speed, and especially reliability, in cognitive tests after selection of three the most informative independent variables in accordance with the standard procedure (standard package STATISTICA 6.0, a stepwise regression analysis).

The data analysis has demonstrated that the general intellect (IQ) had the high relationship with strength and functional mobility of nervous processes, if those indices have been strengthened indices proposed by authors (namely, accounting noise immunity indicators, as well as the verbal and nonverbal intellect) in the 1^{st} group of subjects.

Thinking ability had the higher relationship (R = 0.80, $p < 0.01$). At the same time, students-researchers (military psychophysiologists should be researchers) demonstrated much more close dependence in those indices: the general intellect had high relationship with extended FMNP indices (R = 0.82, $p < 0.01$), and thinking ability even higher (R = 0.95, $p < 0.001$). The possible reasons and ways of application are discussed.

The analysis has been carried out in relation to dependence of the intellect (verbal VI and non-verbal NI components) on the features of the subjects' nerve system during cognitive activity.

The results of measurements demonstrated that partial coefficients of correlation were not very high (not higher than 0.6) for both VI and NI in both groups: medical care professionals (Fig. 1) and psychophysiologists-researchers (Fig. 2).

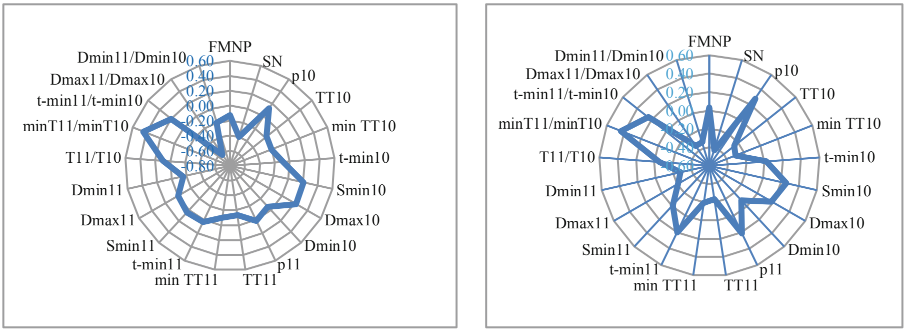

Fig. 1. Correlations histograms of the verbal (left) and non-verbal intellect (right) with features of the nervous system in cognitive test performance (medical care professionals)

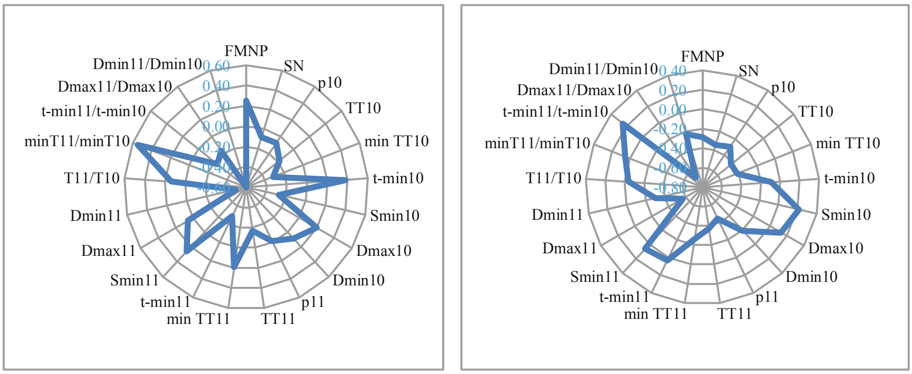

Fig. 2. Correlation histograms of the verbal (left) and non-verbal intellect (right) with features of the nervous system in cognitive test performance (psychophysiologists)

Low level of the relationship of FMNP and SN with the intellect has been revealed in both groups. At the same time, the highest relationship was demonstrated in both groups in relation to maximum work pace ($r > 0, 4$), especially for the ratio of interference immunity f_4. Besides, psychophysiologists demonstrated higher relationship of the intellect with the performance rate.

To study if not alone indices of the nerve system of a human, but their joint impact could have high relationship with the intellect components, the further analysis was carried out: multiple correlation has been measured applying the forward stepwise analysis selecting three the most informative indices of the properties of higher nervous activity.

It has been revealed that the relationship for medical care professionals was above the medium level (VI: $r = 0.72$, $p < 0.01$; NI: $r = 0.63$, $p < 0.05$) and informative indices included ratio f_2, f_4 and SN. The relationship for psychophysiologists was higher (VI: $r = 0.79$, $p < 0.01$; NI: $r = 0.90$, $p < 0.01$) and informative indices were rate and reliability of the test performance.

As it is generally recognized, the intellect as a mental tool is not enough for the cognitive activity [11]. A way and type of thinking can play more significant role in practice [12]. To compare their relationship with the nerve system traits, we studied such a relationship between intuition and thinking features of subjects the same groups applying the same technique (the forward stepwise analysis selecting three the most informative indices), as it was described above.

It is necessary to highlight that relationship of general thinking ability was higher in the first group (medical care professionals) than in psychologists ($r = 0, 6$ and 0,4 accordingly). I.e., it is possible to make a decision that practical experience is more important in such type of cognitive tasks than features of the nerve system.

By selecting the 3 most informative independent variables according to the standard procedure, a stepwise regression analysis revealed: the coefficient of multiple correlation of the test intellect (index corresponds to the type of intellect) $R_{VI} = 0.7 \ldots 0.93$ ($p < 0.01$), $R_{NI} = 0.95 \ldots 0.97$ ($p < 0.001$).

4 Conclusion

The technique of studying the stability of cognitive abilities of high school students has revealed significant fluctuations in the speed and reliability of simple cognitive test tasks.

A strong correlation between subjects' cognitive test activity and individual properties of their cardiovascular and nervous system, as well as energy regulation and solar physiological parameters (speed and density of solar wind) has been revealed ($R = 0.88 \ldots 0.91$, $p < 0.01$).

Identified features of cognitive activity require further investigation and clarification of the mechanisms of regulation of such activity.

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Understanding Junior Design Students' Emotion During the Creative Process

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Abstract. The discussion of the relationships between emotional concerns and design had to be conducted for over twenty years. However, most of the discussions still focus on how emotion would influence the feature of design outcomes or how to understand the users' emotional concerns. Limited investigations are conducted for optimising the design process. Especially to the junior designers and junior design students, a niche need for helping them to manipulate their emotional concerns is discovered. This study aims to seek some methods to lead junior design students understanding their design processes which would be influenced by their emotional changes. It is expected that the proposed methods would help students to identify their emotional concerns and forest them to make decisions more effectively.

Keywords: Emotion design · Design process · Emotional concerns · Decision-making · Design evaluation

1 Introduction

There are growing concerns on the inter-relationships between humanity and design among design scholars for the last twenty years. Some design scholars proposed the concept of design and emotion. Summarised the prior studies, emotional concerns potentially would influence the experience of design and the design process. Consequently, those junior designers would obtain a relatively more apparent influence of emotional concerns during their design process than experienced design professionals. The emotional concerns influenced junior design students' information processing about their experience and knowledge development. Junior design students may encounter emotional concerns during the manipulation in the process of innovation, and these emotional concerns may influence their judgment and evaluation. This reflected that the influence of emotional concerns on decision -making is based on the initiative. The above literature findings provided insight that emotional concerns could influence the design process. According to the literature review, a niche need for investigating the changes in junior design students' emotions during the design processes or how their emotional concerns affected the design process is discovered. Some developed design processes are suggested to design students; however, junior design students are still having difficulties in manipulating the design process in their design studies even when they learned management

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and materials allocation skills. Moreover, junior design students show themselves to be weaker in processing the received information from objects that involved many human interactions when their innovation process is only made up of rational and logical considerations. Alternatively, their innovation process includes the techniques, experience, and junior design students' responses towards the external environment or stimulants around them. Hence, the above literature review provided evidence that those 'intrinsic factors,' including emotion or affective systems, can influence junior design students' judgment and design evaluation in the design process.

2 Emotionalise Design Process

In the past decades, some scholars have shown their concerns on the relationship between humanity and design. Some of them linked up the concept of emotion and design [1–3] for understanding how the design would work for providing a pleasurable design experience [4, 5] to users [6, 7]. These investigations were then developed as the fundamental concepts of design and emotion and most of the studies were conducted according to users' perspectives [8–10]. At the same time, some studies provided insights that emotional changes are human responses to the environment around them and influence people's judgements. Some design scholars took this insight into design studies as a reference and proposed that emotional changes perhaps not only influence the experience of design [11, 12] but also the design process. They proposed that the influence of emotional changes on judgment would be affected by experience and knowledge. Consequently, those junior designers/students would obtain a relatively more obvious influence of emotional changes during their design process than experienced design professionals. Hence, some junior design students may encounter emotional changes during the manipulation [13, 14] in the process of innovation and these emotional changes may influence their judgement and evaluation [15, 16]. Maybe this reflected that the influence of emotional changes on decision-making is based on initiative. At the same time, it provided insight that emotional changes could influence the design process. However, few investigations discovered the changes in junior design students' emotions during the design processes [17, 18] or how their emotional changes affected the design process [19, 20].

Some innovative design processes were developed for facilitating a more manageable and productive result. These design processes focused on, for example, management aspects, materials allocation aspects, and so forth. However, it was found that junior design students could still have difficulties in manipulating the design process in their design studies even when they learned management and materials allocation skills. Moreover, junior design students showed themselves to be weaker in processing the received information from objects that involved many human interactions. This reflected that the process of their innovation is not only made up of rational and logical considerations; besides, it includes the techniques, experience and skills of the designers and even their responses towards the external environment or stimulants around them. Their responses to the external environment can be regarded as emotional responses [21]. Hence, the 'intrinsic factors', including emotion or affective systems, can influence designers' judgement and evaluation in the design process. To become familiar with and realise how junior design students' emotions could affect the process of design, the changes of emotions from junior design students [22] would be recorded and measured. Several assessment tools adopted in the concept of design and emotion [23] – such as facial expressions [24], verbal feedback [25], and so forth – would provide helpful hints for recognising the emotional changes of designers.

3 Decision-Making and Evaluation in the Design Process

Theories related to the linkages of 'Emotion', 'Decision-making' [26] and the 'Design Process' were developed. The previous studies in 'Design and Emotion' were reviewed. The concepts of 'Emotionalised Design', 'Emotional Design' [27] and 'Emotion Design' were also clarified. These close linkages between designers, design outcome and the user/audience in the 'Design and Emotion' aspect were then explained by several frameworks and models (e.g. 3E model [15]) suggested by previous scholars. To further explain how emotions, work with the factors of the 'Design Process', another framework, named the E-wheel model, explained the interactions between internal factors, external factors and emotions and designers. The concept of the E-wheel reflected that after recognising the emotional changes, the junior design students' emotions would be identified. Also, the influence on the performance of the students in their design process in practical terms would be investigated. It was thus assumed that if junior design students would manage their emotional changes with appropriate methods, their decision-making ability would be enhanced. As a result, junior design students would manipulate their processes of design in an effective approach. Therefore, this could optimise the design outcomes. As a result, to investigate some practical guidelines to assist junior design students will enable them to have awareness of their own emotional changes. Consequently, to introduce them to the design process for optimised design outcomes will be very important.

4 Steps for Designing Emotion

There were three main steps for designing emotions. The three steps are identifying, interpreting and adapting. Identifying referred to recognising emotional granularity, intensity and context. Interpreting referred to translating emotion(s) to design without oversimplifying. Adapting referred to continuously evolving the translated emotion(s) as the emotional relationship changes. To process these three steps, design students have to understand corresponding emotional elements and then processing some questions for designing emotion. In the stage of identifying, they have to understand which kind of emotion(s) they would like to stimulate? In the stage of interpreting, they have to understand how they stimulate their audience to evoke the identified emotion(s). In the stage of adapting, the design students have to design how they continuously encourage their audience obtaining the same responses (Fig. 1).

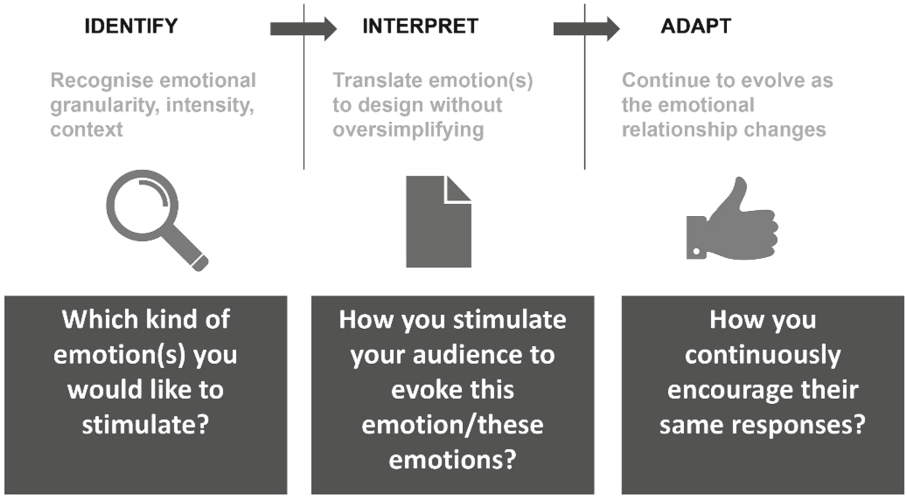

Fig. 1. The figure illustrated steps for designing emotion.

5 Grammar for Visualising Emotions

In this research study, some grammar for visualising emotions were found. Based on the interview and literature review about the perceptions of the visual elements, some typical emotions were selected and assigned as samples for understanding the responses of the audience about them [28]. The project conducted by Ardito, Costabile, Desolda, Lanzilotti, Matera, Piccinno & Picozzi inspired Vavrykovych [29] to further investigate the relationships between emotion and some visual elements. The selected visualising emotions included (as shown in Fig. 2): 'Active, passive, structural solid strong, nonstructural fluid soft, stable, unstable, positive bold, forceful, tenuous uncertain, wavering, the vertical, noble, dramatic, inspirational, aspiring, the horizontal farms, calm mundane, satisfied, primitive simple, bold, effusive, flamboyant, refined, jagged. brutal hard. vigorous masculine, picturesque, curvilinear, tender soft, pleasant feminine, beautiful, rough, rasping, grating, smooth swelling, sliding, decreasing contracting, increasing expanding, dynamic, static focal, fixed'. Based on the investigation, lines are common elements adopted by designers as grammatic principles for visualising emotions.

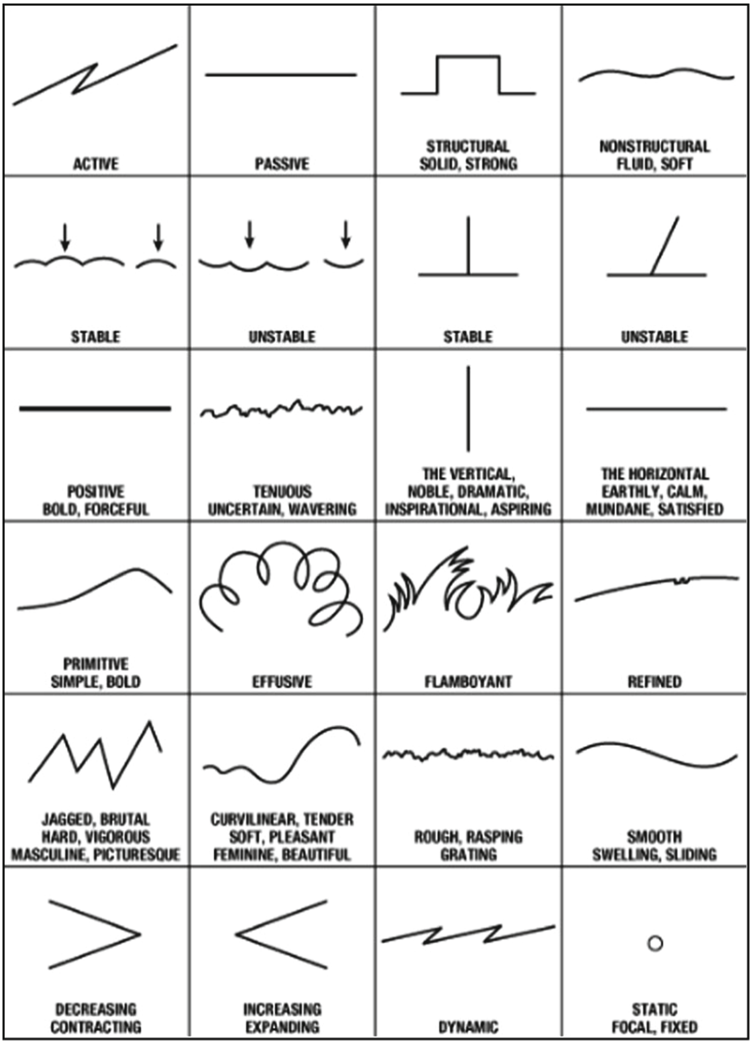

Fig. 2. The relationships of emotion and some visual elements were found and illustrated in the above figure [29].

6 Conclusion

This study aims to lead junior design students understanding their design processes which would be influenced by their emotional changes. Based on this aim, some objectives were proposed. First, some methods for helping junior design students to insert emotional concerns into their design processes were explored. Practical suggestions for leading junior design students to concern their emotions in the design process were proposed. Secondly, the categories and influence of the emotional concerns that would enhance junior design students' abilities to manipulate their design process were investigated. It is expected that the proposed methods would help students to identify their emotional concerns and forest them to make decisions more effectively. Optimised design outcomes would be provided. An indicator would be proposed to designers or design students to alert their emotional concerns and corresponding methods to adjust their emotional responses for enhancing their decision-making ability and manipulation of their design process. It is expected that the finding of this research would provide the foundation for developing guidance to lead junior design students to insert their emotional changes in the design process phase by phase. The findings of this research study reflected that students can notice their emotional changes and express their emotion with more accurate design elements. That means, their decision-making ability was enhanced. The identification of their emotional changes is a possible way to help them evaluate their performance in the design process. Although they recognized that their emotion is related to their performance, their performance did not improve when they are under relatively strong irritability and anxiety. Methods of managing their emotional changes are needed.

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Art Image Complexity Measurement Based on Visual Cognition: Evidence from Eye-Tracking Metrics

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Abstract. In order to obtain the physiological and psychological indicators of the visual complexity of art images from the perspective of visual cognition, this study explored the relationship between eye-tracking metrics and the psychological factors. The study invited 16 participants (8 females, age range 23.81 ± 0.98) to participate in the experiment. In this study, eye-tracking experiments and a questionnaire of psychological factors affecting visual complexity were conducted. The results show that there is a significant relationship between the fixation length, first fixation time and visual complexity. Image with the complexity score interval [74, 100] has a high mental workload on visual processing. There is a significant linear relationship between the fixation count and visual complexity. In addition, the analysis of the psychological scale shows that psychological factors have a positive significant correlation with visual complexity. The participants show sensitivity to the factor of color, texture, and cognitive on visual complexity, but were insensitive to shape factors.

Keywords: Visual complexity · Cognition measurement · Art image

1 Introduction

A series of researches such as image processing and computer vision have been developed. As a basic aspect of visual cognition, visual complexity has important research value in the fields of cognitive psychology.

Image complexity generally refers to the internal complexity of the image. The definition of image complexity is different in various academic sectors. Previous research started with the concept of complexity in composition theory, dividing the complexity of images into global complexity and local complexity, and dividing complexity features into color, texture, and shape [1]. Rump [2] recommends the use of specific dimensions in the study of visual complexity. Kreitler et al. [3] also believe that visual complexity is a multidimensional concept of 5 dimensions. According to Roberts MN [4], visual

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complexity can be explained from 7 dimensions, respectively are element incomprehensibility, element confusion, number of elements, element type, asymmetry, color diversity and 3D appearance.

Image complexity can be used for visual cognition and emotion evaluation research [5]. People have acquired experience in the natural environment, then transfer them to the man-made environment [6]. Human visual cognition is similar to other organisms and tends to process only a part of sensory input selectively [7]. Yanqin et al. [8] evaluated the complexity of gray-scale images based on the image complexity evaluation method of BP neural network, and verified that the algorithm conforms to human visual cognition. Hao et al. [9] proposed that the image features that affect human visual complexity mainly include 3 aspects: the number of colors, the uniformity of the spatial distribution of colors, and the number of objects in the image.

In the research on the visual complexity of art images, Guo et al. [10] proposed a framework for evaluating the visual complexity of paintings, but did not involve the cognitive measurement of visual complexity. In order to obtain the physiological and psychological indicators of the visual complexity of art images, this research explores the relationship between eye-tracking metrics, psychological factors and visual complexity through a method based on cognitive psychology.

2 Method

2.1 Stimuli

In order to achieve idealized results that meet the standard of visual complexity, we chose the open source image data set SAVOIAS provided by Elham et al. [11] as stimuli. The data set contains 1420 images in 7 categories, and the scoring method is to obtain more than 37,000 image labels from 1687 contributors, then converted the paired scores into absolute scores of [0, 100], which have high credibility on visual complexity. The stimuli are selected from the art category in the data set SAVOIAS, with a total of 420 images. All images are verified to conform to the normal distribution by using IBM SPSS Statistics R26.0.

2.2 Participants

The experiment recruited 16 college students from Shanghai Jiao Tong University. The male to female ratio was 1:1, the average age was 23.81 (SD = 0.98), the vision of all participants is normal or normal after correction, and the cognitive level are normal.

2.3 Eye-Tracking Task

The experiment equipment was Tobii T60 eye tracker, screen resolution was 1280 pixels by 1024 pixels, sampling rate was 60 Hz, and Tobii Studio 1.7.3 software was used for programming, generating area of interest (AOI) and recording experimental data. The experiment was proceeded in a quiet laboratory with suitable indoor light.

Participants signed the experiment assignment and kept 60 cm away from the eye tracker to complete the calibration. The experiment started with the experiment guide.

After confirmed, participants could hit the space bar to start the eye-tracking task. The experiment program presents 420 art images in random order, each image is presented for 3 s, and there is a 1 s blank interval between each 2 images. Participants need to try to understand the content of the image while viewing the image in order to achieve the purpose of understanding the complexity of the image.

2.4 Psychological Scaling

Participants were required to fill in a questionnaire on factors affecting visual complexity after completing the eye-tracking task. According to the measurement of image complexity and the research progress of cognitive psychology, the factors are divided into 4 dimensions, which are the following 14 factors: color quantity, color harmony, color contrast, texture roughness, unit texture quantity, shape regularity, edge clarity, shape continuity, familiarity, aesthetic value, degree of abstraction, number of semantic objects, semantic intelligibility and style specificity. Participants need to evaluate on 7-level Likert scale according to the degree of influence of each factor on image complexity.

3 Result

The research results of this article are divided into two aspects, respectively are physiological data analysis and psychological data analysis. First, we analyzed the relationship between the metrics of eye-tracking behavior and visual complexity. In previous studies [12], people with high cognitive demand had longer fixation time and more fixation counts, both of which reflected longer cognitive processing and higher mental load level. Some studies have also found that the average and total time of fixation will increase mental workload [13].

After excluding invalid eye-tracking data, we divided 420 stimuli into 7 groups according to their complexity score and analyzed significance level between fixation length, first fixation time, fixation count and visual complexity.

The study performed Kruskal-Wallis test on fixation time and visual complexity (Fig. 1). Among them, there are significant differences between group 3 and group 7 (Adj. Sig. $a = 0.009$), group 4 and group 7 (Adj. Sig. $a = 0.012$), group 5 and group 7 (Adj. Sig. $a = 0.016$).

The Kruskal-Wallis test of first fixation time and visual complexity showed that there were significant differences between group 3 and group 7 (Adj. Sig. $a = 0.001$), group 4 and group 7 (Adj. Sig. $a = 0.002$), and group 6 and group 7 (Adj. Sig. $a = 0.005$). We drew a pairwise comparison map as shown in Fig. 2.

A One-way ANOVA was conducted between participants to compare the effects on the fixation count of complexity images (Table 1). Under the condition of 7 groups, [$F(1,6) = 2.743$, $p = 0.012$]. The post-hoc comparison from the Tamhane test showed that group 2 was significantly different from group 4 ($SD = 0.130$, $p = 0.046$) and group 7 ($SD = 0.132$, $p = 0.006$). After polynomial analysis, Linear Term ($p = 0.004$) shows that there is a significant linear relationship between the number of fixations and visual complexity.

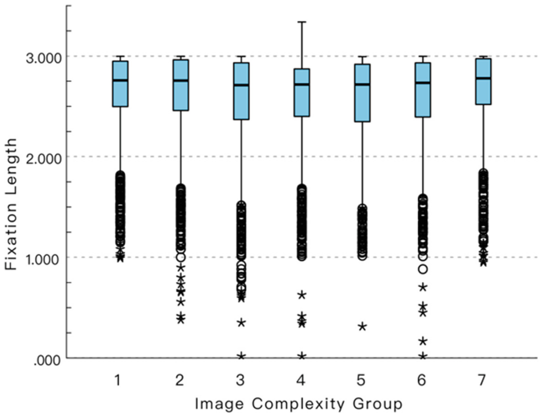

Fig. 1. Independent-samples Kruskal-Wallis test on fixation time and visual complexity.

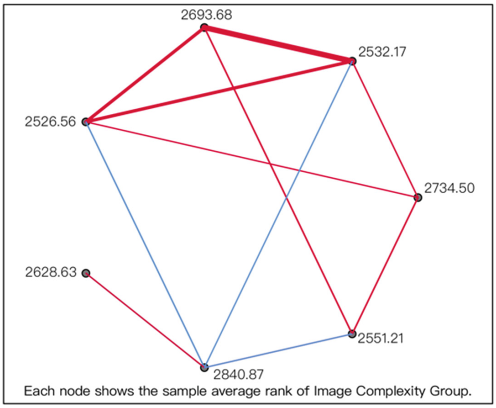

Fig. 2. Pairwise comparison map of image complexity group.

Table 1. One-way ANOVA on the fixation count of complexity images.

(I) ICG	(J) ICG	MD (I-J)	Std. error	Sig.	95% confidence interval	
					Lower bound	Upper bound
2	4	−.398*	0.130	0.046	−0.79	0.00
	7	−.480*	0.132	0.006	−0.88	−0.08
4	2	.398*	0.130	0.046	0	0.79
7	2	.480*	0.132	0.006	0.08	0.88

*The mean difference is significant at the 0.05 level

To further understanding of the influence of participants' subjective psychological assessment on image complexity, 16 effective questionnaires were analyzed (Fig. 3). Through the One-sample T-Test, color (M = 4.750, P = 0.001), texture (M = 4.969, P = 0.002) and cognitive (M = 4.688, P = 0.005) factors have a positive correlation with the degree of visual complexity perception The shape factor (M = 4.458, P = 0.079) has no relevance to the perception of image complexity.

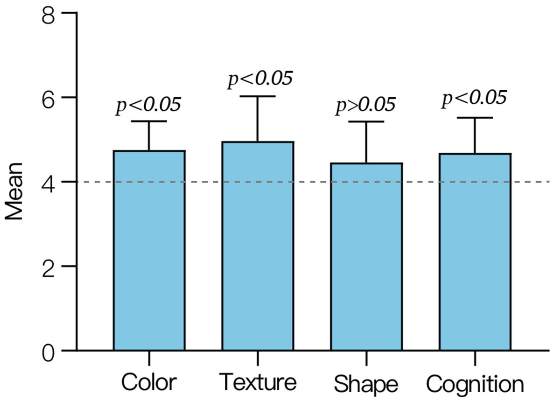

Fig. 3. Box-plot of t-Test on color, texture, shape and cognition factors (test value = 4).

Through Pearson correlation analysis, we found that both the shape factor (r = 0.676) and the cognitive factor (r = 0.852) have a significant positive correlation with the level of visual complexity (Table 2). That is, high visual complexity reflects high level of shape factors and cognitive factors and vice versa. It is worth noting that the positive correlation between shape factors and cognitive factors and the level of visual complexity does not mean that the two factors have significant impact on visual complexity. In addition, the texture factor (r = −0.212) has a negative correlation with the color and cognitive factors (r = −0.075).

Table 2. Pearson correlation on color, texture, shape, cognition factors and visual complexity level.

	Color	Texture	Edge	Cognition	Visual complexity
Color	1				
Texture	−0.212	1			
Shape	0.061	0.091	1		
Cognition	0.232	−0.075	0.364	1	
Visual complexity	0.393	0.210	0.676**	0.852**	1

**Correlation is significant at the 0.01 level (2-tailed)

4 Discussion

This study analyzed the significance level between fixation length, first fixation time, and fixation count and visual complexity. The analysis of fixation length showed that there were significant differences between 3rd, 4th, 5th group and the 7th group. According to the visual complexity level, the complexity score interval of the 7th group is [74, 100]. Image in group 7 are mostly depicted grand scenes and incomprehensible semantics, which have a high load on visual processing. The complexity score interval of groups 3, 4, and 5 is [31, 61], and the pictures are dominated by a moderate number of salient objects and easier-to-understand semantics. It can be seen that the fixation length can reflect the significance between the image with the highest complexity and the image with moderate complexity. The visual workload is significantly improved when viewing the most complex image.

The first fixation time refers to the duration of the first fixation point in area of interest (AOI). There are significant differences between the first fixation time of groups 3, 4, 6 and group 7. Whether the AOI region of the image is significant can affect the first fixation time of participants. Similar to the fixation length, fixation counts also reflects the participant's cognitive processing and psychological load level. There were significant differences between the group 2, 4, 6 and 7. Among them, the significance of the group 2 and group 7 is 0.006, indicating that fixation count is positively correlated with complexity. From the average graph (Fig. 4), fixation count and visual complexity present a relatively good positive linear relationship.

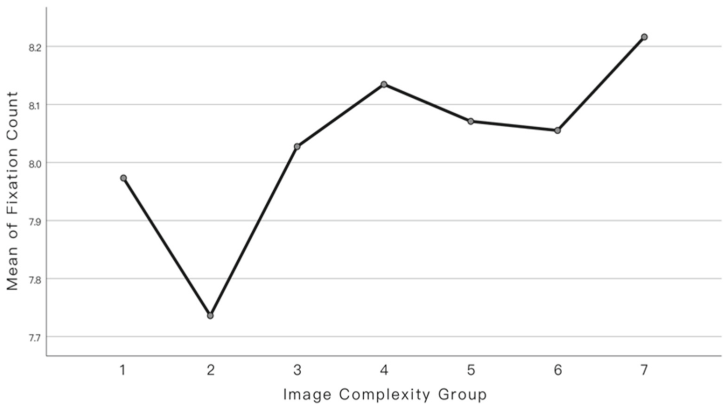

Fig. 4. Mean plot on image complexity group.

In addition to eye-tracking data, the results of psychological scale survey showed that the participants are sensitive to the effects of color, texture and cognitive factors on visual complexity, but are not sensitive to shape factors, reflecting that the cognition process of shape in human visual system is very proficient. When the human visual system recognizes shapes, it mainly recognizes objects by first recognizing the salient parts [14]. People can make quick and accurate judgments of objects through the prominent visual parts.

In addition, the positive correlation between shape factors, cognitive factors and the level of visual complexity implicates that from the perspective of visual complexity, more attention should be paid to the level of image shape features and human psychological characteristics. Previous studies on visual complexity started from human psychological factors and explored whether the image complexity algorithm meets human psychological expectations. This research has verified the positive and significant correlation of psychological factors to the level of visual complexity through correlation tests. Follow-up research will continue to study the significance of the influence of various psychological factors on the perception of visual complexity.

From the perspective of complexity science, this study explored the level of correlation between eye-tracking metrics, physiological indicators and visual complexity. The measured feature indicators pertain to the basic features of the image. The differences in the perception of image complexity by high-level features such as semantics and style have not been analyzed. Future research will collect more data on significant influencing factors, establish a regression model between eye-tracking behavior and visual complexity, calculate a wider range of art images, and evaluate the complexity of art works from the perspective of recognition.

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Neurobusiness Applications

Attentional and Emotional Engagement of Sustainability in Tourism Marketing: Electroencephalographic (EEG) and Peripheral Neuroscientific Approach

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Abstract. In recent years, sustainability has received significant interest from companies and structures that have adopted new marketing and business models to improve the living conditions of the environment and consumers. Given the growing interest and attention, the issue of sustainability has been investigated by different disciplines, such as neuroscience, which have proved useful for investigating the emotional responses and cognitive processes of individuals, allowing us to understand the relationship between consumers and sustainability better. In this regard, this paper offers an overview on the topic of sustainability in a specific sector, such as tourism marketing, on the use of neuroscience to investigate sustainability and on the application of a multimethodological paradigm, involving the use of electroencephalography (EEG) and biofeedback, to measure individuals' electroencephalographic and autonomic activity during the exploration of a green hotel.

Keywords: Sustainability · Tourism marketing · Neuroscience

1 Sustainability in Tourism Marketing

In recent years, the topic of sustainability has been an area of great interest for many disciplines, such as ethics, philosophy, psychology, social and cultural sciences, technology, and politics [1–3].

In particular, cultural and social changes, new laws, regulatory changes and the development of new technologies have led to new and primary attention around this topic. Indeed, sustainability is configured as a series of processes that individuals implement to improve their quality of life while, at the same time, protecting the environment and environmental resources.

The growing interest and attention for this topic have led structures and companies to adapt their business models and find solutions suited for the new emerging issues in terms

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of sustainability management. Sustainability management involves the implementation and formulation of possible actions that support sustainability from an environmental and socio-economic perspective [1, 4]. Therefore, many sectors, including tourism, had to gear up to manage sustainability. In particular, the tourism sector, which is often perceived as being driven by promotional marketing and aimed at selling places to consumers, is instead configured as a broader process aimed at managing its negative effects, reducing the possible consequences and impacts on the environment and people and the optimization of benefits, considering environmental, cultural and social factors. In this perspective, the tourism sector had to consider the sustainability matter to adopt new forms and marketing approaches, such as the eco-green one [5], in order to make a profit while improving the quality of life of people and the environment.

2 Neuroscience to Investigate Sustainability

As highlighted in the previous paragraph, the emerging attention for the sustainability topic has brought consumers and businesses to adopt new solutions. In the light of previous research [6–8], the use of existing methods and traditional measurement techniques did not fully comprehend consumer behavior regarding sustainability.

Despite traditional methods and existing techniques, neuroscience has made it possible to open new frontiers in the investigation of consumer behavior towards sustainability, offering greater precision in the measurements of collected data [9].

Indeed, neuroscience, which is configured as a multidisciplinary science, has made it possible to integrate the traditional research tools with the use of new and different neuroscientific techniques for the investigation of consumer behavior, such as electroencephalography (EEG), which allows the recording of cortical activity of individuals which is informative on different cognitive processes such as perception, emotions, and memory [7, 10, 11], the biofeedback, which allows to record the electrodermal activity, which is a useful metric for the level of emotional engagement [7, 12] and eye-tracking, which makes it possible to detect individuals' ocular behavior [7, 13, 14], thus constituting an important tool capable of analyzing individuals' behavioral and cognitive correlates. In particular, the use of these different neuroscientific techniques allows obtaining more information on consumers' behavior at a conscious and unconscious level, investigating their emotional and cognitive responses [7, 12]. In this sense, the contribution and possibilities offered by neuroscience could contribute to the investigation of the sustainability topic, allowing to obtain data that helps the implementation of a sustainable oriented approach characterized by the use of sustainable practices and of eco-sustainable products and materials, and also for greater awareness in relation to the green approach [15].

Furthermore, neuroscience could help providing more information and a better understanding of the cognitive and emotional correlates that influence consumer behavior and explaining and describing the possible barriers which limit the acceptance and reduce positive behaviors related to the circular economy's concept and practices [16]. Finally, the use of neuroscience would allow stakeholders to acquire greater awareness of the strategies that should be adopted to promote sustainability, with greater accuracy in targeting sustainable products and in the identification of organizational sustainability attributes that generate negative or positive emotions [7, 16–20].

In light of these positive aspects, the use of neuroscience applied to tourism, defined as "neurotourism", has so far been investigated by a limited number of researches [21–23] which have observed the tourists' behavior by mostly investigating their brain and ocular behavior through the use of EEG and eye-tracking [16, 23, 24].

These ones and other first empirical studies are examples of attempts of applying neuroscience in tourism [22, 25–29] and show the possibility and the need to use a more systematic neuroscientific approach for the management of tourism marketing [16], in order to implement more appropriate strategies to improve the condition of individuals and the environment.

3 A Neuroscientific Approach to Investigate Sustainability in Tourism Marketing

In order to demonstrate how the green marketing and sustainability can benefit from neuroscience and to highlight as such approach can foster the comprehension of emotional and attentional states in the consumer, this paragraph will describe the application of a multimethodological neuroscientific paradigm to investigate the cognitive and emotional responses of individuals during the exploration of a green hotel. Indeed, by using a multimethod perspective, it is possible to gather neurophysiological data while participants are asked to explore a certain set of stimuli.

In particular, we have conducted an experiment where, in order to get an adequate comprehension of the consumer, both central and peripheral data was collected by using EEG and an autonomic system in a green hotel structure, where sustainable and environmental themes are the core components. Specifically, 19 healthy participants, after the montage of the tools (EEG and biofeedback) to monitor the neural and autonomic activity, were asked to accomplish a standardized task consisting of exploring four different environments or "areas" (restaurant, bedroom, hall and bar) which presented eco-friendly elements, such as zero-km products, sustainable clothes and eco energy systems.

Regarding the data recording a 15-channel EEG tool (LiveAMP, Brain Products, München, Germany) and a biofeedback device was adopted (Biofeedback 2000 x-pert, version 7.01, Schuhfried GmbH, Mödling, Austria). For the EEG, power data was computed by fast Fourier transformation (FFT) for standard frequency bands delta (0.5–4 Hz), theta (4–8 Hz), alpha (8–12 Hz), and beta (14–20 Hz). For the autonomic activity the following metrics were calculated: Hear Rate, Skin Conductance Level (SCL), Skin Conductance Response (SCR), Pulse Volume Amplitude (PVA) and Blood Volume Pulse (BVP).

The integration and application of these different neuroscientific tools allowed us to observe differences in cognitive processing and in the level of engagement of individuals during the exploration of the environment characterized by the adoption of an eco-sustainable approach. In particular, an increase in individuals' attention and emotional engagement, highlighted by an increase in temporoparietal beta and theta EEG activity, has emerged during the exploration of the green hotel environments. Also, for peripheral activity, an increase in involvement and positive emotional engagement, evidenced by an increase in PVA and HR activity, has emerged during the exploration of specific green hotel environments, providing information on some specific elements of the environment that caused a positive response in the individual. Collected data in this research design is relevant for the understanding of the consumer from a multifaceted perspective.

4 Discussion and Conclusions

This work aimed to prove the value which the neuroscientific approach could provide to the sustainability cause for touristic marketing and, more in general, for the eco-friendly movement. As we pointed out, the collection of central and peripheral data can be insightful regarding the consumers' attentional and emotional states exposed to sustainability-related stimuli.

Indeed, evidence collected by the recording of EEG activity can provide information about individuals' attentional level, the processing of specific targets or stimuli (e.g., [30]), and on the use of feed-forward mechanisms for the processing of information regarding individuals' purposes and personal objectives [31]. This allows for a better understanding of the state of cognitive consonance or dissonance induced by the sustainability orientation. Furthermore, the recording of EEG activity can provide information from an emotional perspective, allowing a better understanding of the individual's level of engagement concerning sustainability. Indeed, for example, the activity of low-frequency bands, as theta or delta band in the parietal area, is generally connected to emotional fluctuations, triggered by personal preferences [32] and emotional engagement [33] and more specifically visuo-spatial working memory activation [34], as an emotional response to the environment exploration.

In addition to EEG activity, also the autonomic one, consisting of the recording of electrodermal and cardiac activity, can provide information about individuals emotional arousal [35] and the experiencing of strong emotions [36], allowing to obtain more information on the effects that the adoption of a sustainable approach can have on individuals.

Therefore, as shown in this work, neuroscience is a framework that provides a novel perspective on the consumer, considering dimensions such as attention, emotions, emotional engagement, which make possible the study of conscious and unconscious responses [37]. One of the distinguished reasons to adopt such approach for tourism is its multidisciplinary core, which goes back to psychology, medicine, and social sciences in general. Ultimately, we believe that a successful form of tourism is one that understands the customer needs and integrates the cultural and behavioral aspects and the neurophysiological perspectives.

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The Face of Bad Advertising: Assessing the Effects of Human Face Images in Advertisement Design Using Eye-Tracking

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Abstract. Visual messaging has been widely researched in psychology and communications specifically within the area of advertising [2, 3]. Such messaging research seeks to identify the characteristics and variables within an advertisement that contribute most to its effectiveness [4]. The present study aimed to investigate the relationship between the presence of a human face image in print advertising and viewer affinity for ad content. Thirty-three participants were instructed to preview 42 different personal injury law firm advertisements. Mean eye gaze fixation durations were recorded within both text and image areas of interest (AOIs). Additionally, self-reported advertisement ratings were used to stratify ads into low and high-affinity categories. Findings from the study indicate that there was less time spent engaging with text content in poorly rated advertisements when an image of a human face was present. Interestingly, this effect was not present in advertisements with favorable ratings, where longer fixation durations were dedicated to text AOIs as opposed to image AOIs regardless of the presence of a face image. These results suggest that negatively perceived human faces may impact the perception of an advertisement's message and demonstrates that combined eye-tracking and self-reported measures can provide a comprehensive neuroergonomic assessment of advertisement preference and engagement in real-world environments.

Keywords: Eye-tracking · Advertising · Human face perception · User experience design · Neuroergonomics

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1 Introduction

Print advertising accounts for more than a quarter of total global advertisement spending and human face depiction in this medium is extensive [5]. As it has long been known that human perceptual processing is uniquely affected by human facial features [6, 7], it should be no surprise that consumer behavioral research has focused on the role of the human face in ad design, demonstrating increased brand recognition, improved attention capture and heightened product preference for print advertisements containing face and pareidolian (human face-like) images when compared to their faceless counterparts [1, 8]. But have these findings incorrectly assumed that all faces are created equal? To date, advertising studies have sampled content exclusively from databases of commercial images that employ model actors and actresses, unequivocally skewing results and conclusions in the positive direction. While this may not raise a concern for large-scale corporations toting inanimate services and products, what about the critical advertising niche that exists for individuals and entrepreneurs that rely on self-promotion and name recognition for their success (e.g., politicians, doctors, lawyers)? Will their faces necessarily boost their value and appeal even if deemed disagreeable by societal and commercial standards? Even worse, what if a 'bad" face effectively imposes a deleterious effect on an advertisement's messaging content, repelling the audience that it intended to inspire?

This study sought to provide a novel test of the effects of self-promoting (non-celebrity) human face images on viewer advertisement preference by way of eye-tracking fixation duration data and self-reported measures. As gaze mean fixation duration has been previously demonstrated as a correlate of viewer engagement [9, 10], it is ideally suited for this neuroergonomic assessment which aims to understand the factors that contribute to human behavior in everyday settings and activities [11–14].

2 Methods

2.1 Participants

Thirty-three participants (20 female, mean age = 29 years) volunteered for the study. All confirmed that they met the eligibility requirements of being right-handed with vision correctable to 20/20, did not have a history of brain injury or psychological disorder, and were not on medication affecting cognitive activity. Prior to the study, all participants signed consent forms approved by the Institutional Review Board of Drexel University.

2.2 Experimental Procedure

The experiment was performed over one 45-min session. After giving consent, participants were seated approximately 70 cm in front of a single 27" computer monitor on which they completed a 5-point calibration procedure using the Aurora Screen-Based Eye Tracking Module at a 1920 × 1080 screen resolution before being instructed to view 3 different (evenly distributed) types of personal injury law firm advertisements (42 total) that were either image heavy, text heavy, or balanced based on text to image ratio calculations (text pixels/image pixels). A subset (10) of the advertisements contained the face of an attorney. Image presentation was pseudorandomized across subjects and the calibration procedure was repeated after 21 advertisements were viewed. Participants were instructed to, "View each advertisement carefully" for up to 20 s before rating the ad (Likert scale, 1 = strongly disagree 7 = strongly agree) based on (a) advertisement likeability (b) trust of advertisement content and, (c) intention to contact the advertised law firm if needed. These ratings were then used to further stratify the advertisements into Low Affinity and High Affinity ad categories.

2.3 Eye Tracking Procedure and Analysis

Based on previous literature utilizing eye trackers in attention and engagement research, average fixation duration was selected as the metric most suitable for our experimental question [9, 10]. Binocular gaze data were collected using a Smart Eye Aurora remote eye tracker, which uses infrared light to record where a participant is looking on the screen at a sampling rate of 60 Hz. Using a remote eye tracker opposed to head-mounted eyewear allows for the researcher to study participants in a way that is similar to how consumers would naturally view advertisements. The Aurora Screen-Based Eye Tracking Module was used to conduct a calibration procedure before Ogama open-source recording software was used to collect recordings of gaze data during the data collection process. The Ogama software's fixation calculation is a fixation detection algorithm published by LC technologies (www.eyegaze.com/doc/FixationSourcecode.html). It is a dispersion-type algorithm with a moving window [15]. Prior to the fixation calculation, the fixation detection algorithm applies a filter, omitting samples with both *x*- and *y*-coordinates equal to zero, which often marks the eye tracker output during a blink, and omits samples that lie out of the screen [16]. Fixations were defined as the periods during which eye movements did not exceed 30° per second for a minimum of 100 ms. The *x, y* screen coordinates of each fixation were calculated by averaging all gaze positions within a fixation, and text and image AOI fixations were labeled based on coordinate locations.

3 Results

Eye-tracking results are summarized in Fig. 1. comparing the mean fixation duration time allocated to either Image or Text AOIs for Low Affinity and High Affinity advertisement groups when a human face was present within an advertisement. A main effect is observed for both Ad Affinity ($F_{1,959} = 8.52$, $p < 0.01$) and AOI type ($F_{1,959} = 3.64$, $p = 0.05$) and post-hoc analysis reveals a significant interaction between Low and High Affinity ads for both duration spent in Image AOIs ($F_{1,959} = 2.73$, $p < 0.05$) and duration spent in Text AOIs ($F_{1,959} = 6.46$, $p < 0.05$).

Next, Fig. 2 shows a comparison of the mean fixation duration time allocated to either Image or Text AOIs for Low Affinity and High Affinity advertisement groups when there was no human face present within an advertisement. Here, a main effect is observed for AOI type ($F_{1,1225} = 4.99$, $p < 0.05$) but not for Ad Affinity.

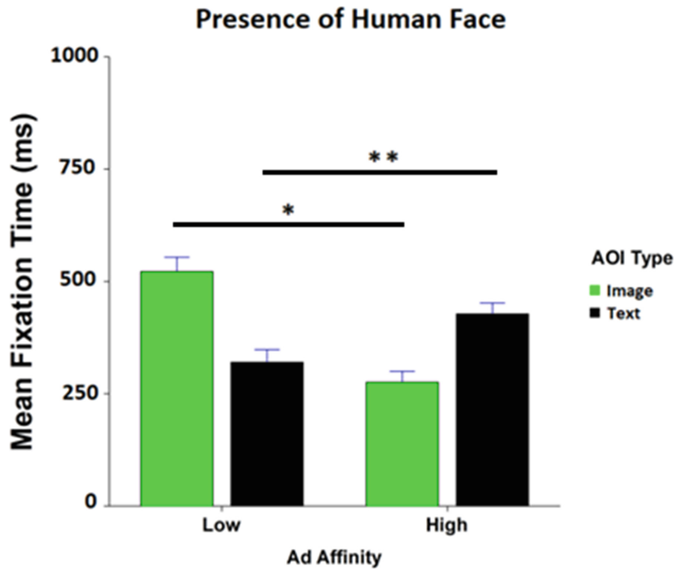

Fig. 1. Eye-tracking results: Comparison of mean fixation duration time (msec) allocated to either Image or Text AOIs for Low affinity and High affinity advertisement groups when a human face was present. Whiskers are standard error of the mean (SEM).

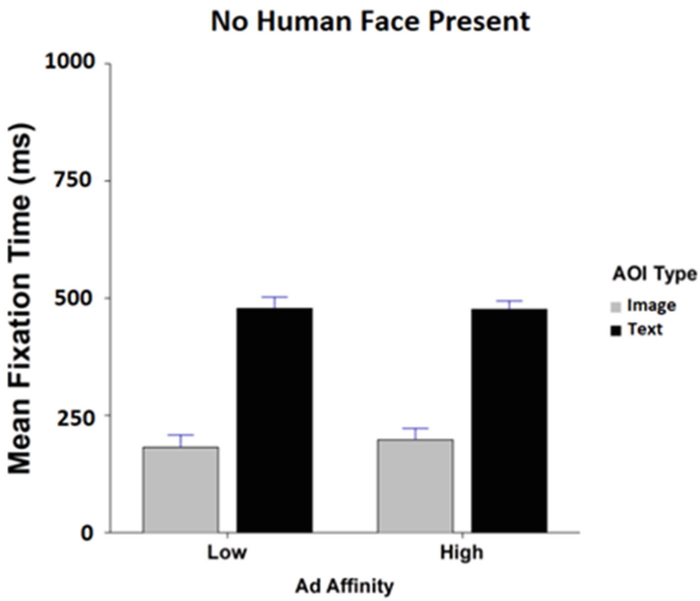

Fig. 2. Eye-tracking results: Comparison of mean fixation duration time (ms) allocated to either Image or Text AOIs for Low affinity and High affinity advertisement groups when no human face was present. Whiskers are standard error of the mean (SEM).

4 Discussion

As human faces and human facial features communicate a number of visual signals that have enhanced effects on human attention [17], advertising research has consistently interpreted these findings as evidence that the human face and pareidolian images have unambiguously enhanced advertisement effectiveness [8]. In this study, we question this claim, and suggest instead that not all faces command increased preference, specifically, for self-promoting personal injury law firm print advertisements. Using the eye-tracking based metric of mean fixation duration within text and image AOIs along with self-reported ratings of viewer advertisement affinity, results indicate that for advertisements with Low Affinity ratings, viewer fixation durations were allocated significantly higher towards the advertisements image content, with lower engagement observed for the advertisements text-based messaging. In contrast, highly rated advertisements had significantly greater fixation allocation for text-based messaging content compared to the poorly rated, Low Affinity ads. Finally, no differences were seen between Low Affinity and High Affinity ads where no human face was present, as text AOI versus image AOI fixation allocation differences were not observed.

In conclusion, this study highlights the use of remote eye tracking in real-world advertisement and marketing analysis. Our initial results are in support of the hypothesis that not all face images improve viewer advertisement preference. These findings warrant further investigation into the relationship between visual face perception and its effect on viewer advertisement engagement and influence.

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Interpersonal Synchrony Protocol for Cooperative Team Dynamics During Competitive E-Gaming

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Abstract. The performance of a team is tightly connected to how well its members communicate and collaborate while working towards shared objectives, a process known as group cognition. In competitive team sports, strategic and efficient coordination between team members often makes the difference between success and failure. Professional e-sport gaming, in particular, requires competitors to engage in quick decision making, strategic thinking, and fast reaction times in order to outmaneuver the opposing team. Interpersonal neural synchrony (INS) is one proposed mechanism by which team members may achieve mutual understanding necessary for successful teaming. However, it is unknown how such measures relate to team performance and how they are affected by gaming environments (in-person vs. remote gameplay). Here, we describe a study protocol aiming to investigate the relationship between inter-individual neurophysiological measures and successful teamwork of two-player teams in Overwatch, a competitive team-based first-person shooter (FPS). The objective of this study design is to relate behavioral and subjective measures of team performance with underlying neural and physiological activity during both in-person and remote sessions of cooperative gameplay.

Keywords: E-Sports · Cooperative teaming · Team performance · Functional Near-Infrared Spectroscopy · Hyperscanning · Neuroergonomics

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1 Introduction and Background

In everyday life, both at home and at work, many goal-oriented tasks are often unachievable by an individual acting on their own. Realization of more complex pursuits often rests on the ability of humans to successfully communicate, designate roles, intuit the situation, and coordinate with other members of their group. However, the "secret ingredients" for team success are often seen as somewhat elusive and the subject of much debate. Comparatively, there is a common consensus that just as an effective team is much more capable than its members alone, and research has demonstrated that successful cooperation requires more than merely the presence of a few people with relevant knowledge [1].

Because collaborative teamwork is such an everyday feature in life, improving team effectiveness is seen as a means of boosting productivity, safety, and even satisfaction of team members. However, the need for effective team performance becomes extremely important when the cost of failure is extremely high. These situations can be readily observed for high-stress professions in which rapid response, seamless coordination, and informed strategic decisions must be made including emergency medical services, first-responders, and military engagements [2–4]. A similar requirement is observed in competitive sports where a winner-take-all model drives the margin between success and failure to become extremely thin and attention to intra-team interactions becomes even more critical [5].

Over the past few decades "electronic sports" in organized competitive video game competitions has grown into a multimillion dollar industry with substantial prize winnings, sponsorship, and audience sizes [6]. Professional e-athletes can easily be compared to traditional professional athletes in their drive and dedication, typically training for hours a day, employing professional coaches, and receiving financial compensation from both prize money and commercial sponsorships [7]. Both practice and tournament play can involve hours of nearly uninterrupted cognitive engagement, placing demands on mental endurance as well as corresponding physical demands. Significant changes in peripheral physiological measures have been reported after even single sessions of e-sport gameplay [8]. In such tightly competitive and demanding environments, both the cognitive demands of gameplay and their interplay within team members and behavior play pivotal roles in overall team performance [9].

Contrary to the perception of video games as cognitively "lazy", the mental skillsets most needed to excel in competitive gaming can include a diverse range of abilities that may vary with the genre of the game in focus [10]. There are also an increasing number of studies which show that video game players have improved attention spans, better spatial reasoning, greater problem-solving skills, and enhanced hand-eye coordination [11]. There can be little doubt that gamers presenting these skills have an edge over their opponents in a competitive environment [12], although there is substantial debate regarding whether gaming simply attracts individuals who have higher baseline cognitive abilities or actually acts as a "brain booster" which confers these advantages [13]. Interestingly, despite mixed evidence regarding the transferability of videogame-related skill improvements, there exists convincing evidence that cooperative gaming is pro-social activity which can increase team cohesion and productivity in subsequent cooperative tasks [14].

Despite decades of research into the constituent components of teaming, little is known about the underlying brain functions which enable cooperation. This is rapidly changing with the introduction of newer non-invasive neuroimaging devices which can monitor brain activity in a non-intrusive manner consistent with a neuroergonomic approach [15]. These advances have facilitated hyperscanning studies, the simultaneous neuroimaging of multiple participants, as a means of understanding interpersonal neural dynamics. Exploring team-based cognition through hyperscanning studies promises to shed light on many of the hidden mechanisms of teamwork [16] and aide in answering many open questions about what empowers a good team.

2 Methodology

2.1 Experimental Overview

In this study we attempt to investigate the neural underpinnings of successful teaming, its relationship to individual cognitive ability, and the influence of environment on teaming (remote vs in-person). To do this we have developed a two-person hyperscanning study during which both members of the team are monitored continuously using functional Near-Infrared Spectroscopy (fNIRS) and peripheral physiological measures such as Electrodermal Activity (EDA). Teamwork success will be measured during the performance of a PC-based competitive first-person shooter, Overwatch, developed by Blizzard-Activision.

Recruited participants will be consented prior and surveyed according to their gaming backgrounds and Overwatch skill levels as well as their occupational experience (civilian and veteran populations). Participants will be matched with other individuals of similar skill levels and both individuals will participate in the experiment during a single session.

The experimental protocol will be divided into three Parts:

Part 1 will consist of an “individual” session in which players are baselined according to their performance on a psychometric cognitive test battery and a single-player performance of the game against in-game AI opponents.

In Part 2, participants will be paired together into dyads to play a cooperative match together against AI-controlled opponents. At this stage, dyads will be divided into one of assigned two groups. In one group, participants will continue to play while seated in separate rooms from each other. While in the second group participants will be introduced to each other in person and seated across from each other to play together (in the same room).

In Part 3, participants who played separately will be introduced and will continue to play seated across from each other (in the same room). Participants who had met previously in Part 2 will be moved to separate rooms to continue gameplay.

Participants will be given short breaks in-between each Part. Experimental groups will be counter-balanced in order to account for the effect of environmental order. Experimental outline is presented in Fig. 1.

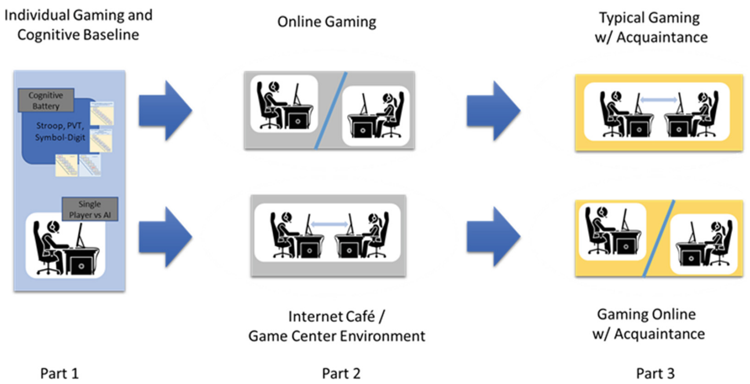

Fig. 1. Experimental protocol phases.

2.2 Experimental Setup

2.2.1 E-Gaming Setup

Participants will play Overwatch on several custom-built gaming machines provided. Each gaming computer setup runs a 64-bit installation of Microsoft Windows 10 Pro and operates on Intel i7-9700k processor, 16 GB of DDR4 memory and an NVIDIA RTX 2060 graphics card. Games will be presented to the participant on a BENQ Gaming monitor with a resolution of 1920 × 1080 and a refresh rate of 240 Hz. Participants will be able to speak to each other through the use of a gaming headset. All conversation will be recorded for use as an additional behavioral assessment.

Custom Overwatch scenarios will be created using the Overwatch Workshop to allow for procedural control of the in-game scenarios. Behavioral and game event information will be logged locally to a file using the Overwatch Workshop Inspector functionality. Game log files will record in-game events including damage dealt/taken, player health, player actions, payload progress and other relevant events.

In order to perform successful integration with and between physiological sources, in-game events recorded in the log file must be associated with local system events. This time synchronization will be performed by registering player inputs from local HID devices on the host game computer (keyboard and mouse actions) and using the action timings to align these inputs with the game events in the Overwatch log file. In addition to generating a local log file of HID input times, corresponding markers will be multi-cast via User Datagram Protocol (UDP) based network communication for low-latency timing information to be captured by adjoint data acquisition (DAQ) computers collecting both neurophysiological data via fNIRS and peripheral measures via EDA devices. Overwatch game in each game computer will connect with the Overwatch server via combination of Transmission Control Protocol (TCP) and UDP networking. During the cognitive task-battery, DAQ computer and task presentation computers will send/receive markers only from the proximate computers (e.g.: Game_Computer1 ←→ DAQ_Computer4). Further details regarding the system setup and layout are presented in Fig. 2 below.

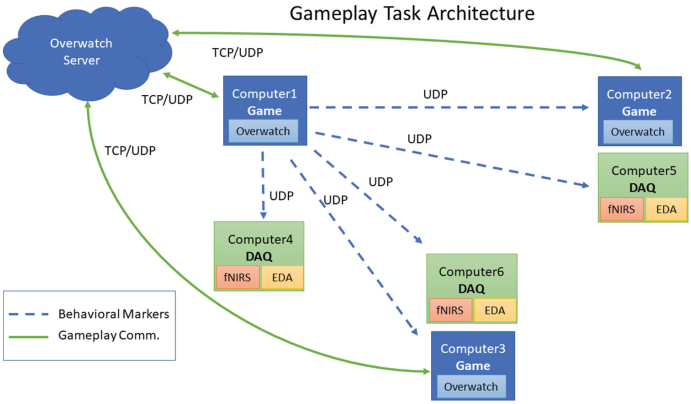

Fig. 2. Time-synchronization diagram for experimental e-gaming presentation computers and physiological data acquisition systems

2.2.2 Neural Measures: Functional Near-Infrared Spectroscopy (FNIRS)

Functional near-infrared spectroscopy (fNIRS) has emerged over the last decade as a new technique to measure brain activity non-invasively [17, 18]. fNIRS uses near infrared light to monitor changes in oxygenated and deoxygenated hemoglobin at the outer cortex of the brain [19]. By employing wearable light sources and detectors, photons are emitted over the scalp that pass by layers of tissue and detectors then collect the fraction of them that return. Because most tissue is transparent to light between 700–900 nm and because absorption is minimal within this optical window, fNIRS systems use multiple wavelengths within this near infrared range. fNIRS is able measure optical density fluctuations caused by metabolic changes in neural activity through a mechanism called neurovascular coupling [20] and can measure the hemodynamic response in a similar fashion to functional magnetic resonance imaging (fMRI). However, fNIRS sensors are wearable, portable, low-cost and possess a higher temporal resolution then fMRI. fNIRS allows subjects to be seated at a computer or in natural postures while monitoring cortical regions such as the prefrontal cortex or motor cortex in a way that is compatible to research surrounding cognitive and motor tasks.

In this study, participants will be monitored using a continuous wave fNIRS system (fNIR Devices LLC) placed over the forehead. Participants with the fNIRS sensor prior to performing each experimental part and data quality will be inspected to ensure that system is calibrated appropriately and that optodes are not occluded. The fNIRS headband will continuously monitor hemodynamic activity in the anterior prefrontal cortex using two NIR wavelengths of 730 and 850 nm recorded at 10 Hz over 16 prefrontal optode locations. Data collection will be performed via COBI Studio software [21].

2.2.3 Peripheral Measures: Electrodermal Activity (EDA)

Electrodermal activity (EDA) is a non-invasive, portable sensor that measures the changes in electrical properties of the skin. The electrical property changes occur due to the electrolytes inside sweat when sweat secretion occurs by the eccrine sweat glands

[22]. Eccrine sweat glands play a key role in regulating thermoregulation and is activated by sympathetic activity of the autonomic nervous system (ANS) [23]. ANS activity is responsible from fight-or-flight response, which reflect bodily arousal and associated with emotional expressions and behaviors in humans [23]. Hence, EDA is considered as an indicator of emotional arousal and processes [24].

Participants will be fitted with two-electrode leads attached to an amplifier (Shimmer GSR+) recording galvanic skin response over the forearm. Data will be collected at 128 Hz and streamed wirelessly to the data acquisition PC for recording and marker synchronization.

2.3 Cognitive Baseline Battery

Individual performance can be expected to be tightly related to measures of cognitive performance. In FPS games such as Overwatch, skillsets such as processing speed, response time, multi-tasking ability and conflict inhibition are paramount to successful gameplay. Therefore, we intend to use these behavioral measures of performance to assess psychomotor cognitive ability and its relationship to gaming performance and qualitative measures of team performance. The battery tasks will include the Stroop Task [25], the Symbol-Digit Substitution Test (SDST), the Psychomotor Vigilance Test (PVT) [29], and the Dual-Search task [30].

2.4 Overwatch Gaming Task

2.4.1 Escort Mode Description

Overwatch is a team-based first-person shooter game which features a number of distinct game modes which players can select from. Of these game modes, the "Escort" game mode was selected as one which was particularly demanding of cooperation. In the Escort game mode, players are placed onto either an attacking or defending team. Attacking players are tasked with escorting a payload across the map through various checkpoints and ultimately to a specific objective location. The defending team is responsible for delaying or halting the progress of the attacking team until the countdown timer for the round runs out. At each intermediate checkpoint extra time is added to the game clock.

Payload progress is accelerated by the presence of multiple attacking team members in the immediate proximity of the payload. Proximity to the payload also causes a slight healing effect. Defending players may also stall the progress of a payload by entering the immediate area. Both attacking and defending teams can employ a variety of strategic approaches to either pin down attacking players or cripple defensive positions. Although character choice adds a significant amount of complexity to the strategies employed, character choice will be restricted to allow for experimental control.

2.4.2 Overwatch Gameplay

The single-player (Part 1) and two-player (Parts 2&3) gameplay periods will consist of eight 3-min sessions of Escort game mode scenarios (termed blocks). Players will spend the first four blocks on either the attacking or defending team and this role will be reversed in the final four blocks. Additionally, each block will alternate between Easy and Hard-AI opponents in order to modulate the difficulty. Player respawn time will be immediate to maintain continuous involvement. Following each gameplay block, participants will be given a brief poll on their perception of their performance, their team and their teammate.

3 Discussion

This paper describes an experimental protocol that aims to evaluate neural underpinning of team performance and factors contributing to successful teamwork. We have designed a new multi-person experimental gaming platform to study cooperation with single-player and multi-player scenarios. Particularly, we will evaluate the impact of cyber or physical presence which is becoming more prominent with the COVID-19 global pandemic. We expect to utilize this experimental protocol with cognitive task battery and e-game scenarios in multiple hyperscanning studies in the near future.

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Assessing the Impact of Ad Characteristics on Consumer Behavior and Electrodermal Activity

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Abstract. The use of mobile, low-cost, and wearable sensors to measure physiological activity, continuously and non-intrusively during everyday tasks has the potential to improve our understanding of human perception, cognition, and behavior at large. One applied field with the practical use of such expansive assessment is consumer neuroergonomics. In this study, we demonstrated the use of ultramobile battery operated and wireless electrodermal activity (EDA) sensors to estimate emotional arousal during the viewing of various out-of-house, printed, and e-mail advertisements of law-firm services. A total of 33 participants' EDA data and self-reported questionnaires were analyzed to assess the impact of different ad types on consumers in terms of their age, gender and prior experience with firms (client vs. non-client). EDA results confirmed as expected that e-mail ads were the least engaging to all participants. Furthermore, participants were engaged significantly less on ads that they are already familiar with, that is existing customers. Results indicate that the use of accessible and low-cost sensors like EDA could be widely deployed to enhance our understanding of customer behavior in order to optimize ad development and delivery.

Keywords: Electrodermal activity · Advertising · Emotional arousal · Consumer neuroscience

1 Introduction

Advertising is defined as a form of communication in marketing with the aim of promoting a product or service [1]. When used effectively, advertising has the potential to

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generate consumer reactions, including emotions and judgments, which are believed to affect consumer purchase intents and decisions [2]. In consumer research, examining the emotional responses of consumers has been essential for understanding the mental processing of consumers in the process of advertisement preference [3]. The techniques used in consumer research to examine consumers' behavior and affective state commonly rely on self-reported measures such as questionnaires and surveys. These measures are easier to implement, as they can capture only the consumers' subjective perception with retrospective thinking and evaluation [4]. However, alongside the subjective part, one's emotional experience triggers distinct physiological patterns [5–10]. Although the impact of advertising on consumers has been measured through self-reported measures in previous studies, the understanding of how advertising influences consumer behavior from a physiological standpoint remains limited.

Technological and neuroscientific advancements have allowed researchers to uncover consumer emotions by studying physiological changes in the body. One of the physiological measures that are relevant to emotions is electrodermal activity (EDA) [11]. EDA, also known as galvanic skin response (GSR), is a portable, non-invasive sensing technique that measures the fluctuations in electrical properties of the skin, most commonly in the form of skin resistance or conductance [11, 12]. EDA changes occur due to eccrine sweat gland activity, which is regulated by the autonomic nervous system (ANS) [13]. The autonomous nervous system is responsible for physiological processes and previous research found that the ANS activity is highly correlated with emotional processes [14]. Due to its relationship with the ANS, EDA has been considered a reliable marker for emotional arousal [13]. In EDA measurements, the electrical properties of the skin can be obtained by applying a low constant voltage or current to the skin via electrodes [15]. The time-series data of skin conductance can be separated into tonic activity (i.e. skin conductance level (SCL)), which is the slower but higher amplitude component, and phasic activity (i.e. skin conductance response (SCR)), which has faster fluctuations and lower amplitude [16]. In previous research, the phasic component of EDA has been utilized as a physiological marker such as assessing judgment and decision-making [17, 18], and consumer behavior in objective/subjective financial risks [19].

In this study, our aim is to evaluate and demonstrate the use of EDA as a tool to examine the effects of advertising on consumers' behavior while observing advertisements of different types such as e-mail, printed media, and out-of-home (billboard) ads, using the event-related phasic component of electrodermal activity.

2 Methods

2.1 Participants

A total of 33 healthy adult participants (20 female participants, mean age = 41.6) volunteered for this study. All participants had the requirements of being right-handed with vision correctable to 20/20. Before the study, consent and background forms approved by the Institutional Review Board of Drexel University were filled and signed by the participants. According to background forms, 18 of the participants (8 females) claimed that they were either a client of a law firm or had experience with them. For EDA analysis, 4 participants' EDA data were either partially or totally excluded due to sensor malfunction.

2.2 Experiment Protocol

The study was performed over a single 1-h session. Participants sat in front of a computer monitor. In the study, participants looked at a total of 56 different ads, each of which was one of the three different advertisement types: out-of-home ads (21 ads × 20 s each), print media ads (24 ads × 20 s each), and e-mail ads (11 ads × 10 s each). Participants first looked at e-mail ads, followed by print media ads and out-of-home ads. E-mail and printed media advertisements were shown for 20 s, while out-of-home ads were shown for 10 s. There were 90-s rest periods between each advertisement type task. While they were observing the ads, the electrodermal activity on their skin was recorded. After each advertisement, the participants were asked behavioral questions in terms of their affinity towards the ads. The questions were on a 7-point Likert scale, with "1" representing low affinity, and "7" representing high affinity. The content of the questions consisted of the viewer's impression about the shown advertisement and firm, and the intention to contact the firm after seeing the ad.

2.3 Data Acquisition, Signal Processing, and Analysis

Throughout the experiment, a portable and wireless EDA sensor Shimmer GSR+ Unit (Shimmer Sensing, www.shimmersensing.com) was placed on the participants' left index and middle fingers for EDA data collection. participants' skin conductance was recorded at a sampling rate of 128 Hz in the unit of micro-Siemens via the EDA sensor. The time blocks where the participants observed the advertisements were synchronized using MATLAB custom scripts. Using the synchronized blocks, EDA data was processed via Ledalab, a MATLAB toolbox for EDA analysis [20]. Before the analysis, EDA data was filtered with a zero-phase 2nd order Butterworth low-pass filter with 0.5 Hz cut-off frequency for pre-processing to get rid of the electrical noise. After pre-preprocessing, continuous decomposition analysis (a method that uses nonnegative deconvolution to separate the components of EDA data) was applied through Ledalab to extract phasic and tonic components of EDA [21]. Average event-related phasic component of EDA data (skin conductance response) over the time blocks where the volunteers observed the ads were extracted as a feature. For statistics of both EDA data and self-reported measures, linear mixed models are used via NCSS.

3 Results

We compared the average skin conductance levels and self-reported questionnaire results for each advertisement type, as well as the participant groups based on gender, age, and customer experience (client vs. non-client). Skin conductance levels indicated the emotional arousal level, while the self-reported measure represents the participants' perceived affinity towards the advertisements.

3.1 Self-reported Ratings

For self-reported perceived affinity ratings, there was a significant interaction between participant's age and their customer experience (F(1,27.6) = 4.38, $p = 0.046$). As seen in Fig. 1a, the self-reported ratings show that there was a significant difference between clients and non-clients across all ads ((*) F(1,32.6) = 24.99, $p < 0.01$), and shown in Fig. 1b, we can see that this trend continues regardless of being male ((**) F(1,25.4) = 12.33, $p < 0.01$) or a female ((***) F(1,37.1) = 10.71, $p < 0.01$). In terms of age, there was no significant difference between the age groups across all ads, however as seen in Fig. 1c, the perceived affinity of younger non-clients was significantly lower than younger ((+) F(1,25.6) = 21.91, $p < 0.01$) and older ((++) F(1,30.7) = 4.99, $p = 0.03$) clients.

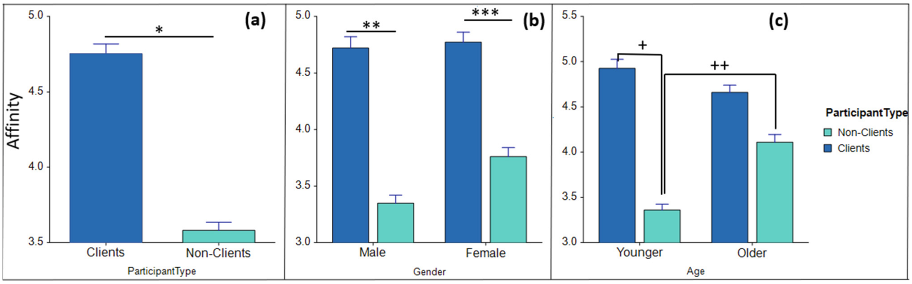

Fig. 1. (a) Average affinity scores according to the customer experience. (b) Average affinity scores according to customer experience in each gender. (c) Average affinity scores according to the customer experience over each age group. Whiskers represent the standard error of the mean (SEM). Significant contrasts are marked over the bars.

3.2 EDA Measures

Overall EDA results show that there was a significant main effect for advertisement types (F(2,1599) = 5.26, $p < 0.01$). There was not a significant interaction between customer experience and advertisement type (F(1,1599) = 1.58, $p = 0.21$). Post hoc results indicated that e-mail ads were significantly less stimulating in terms of emotional arousal than print media ((*) F(1,1593) = 12.81, $p < 0.01$) and out-of-house ads ((**) F(1,1593) = 7.16, $p < 0.01$), as shown in Fig. 2a. As seen in Fig. 2b, in terms of consumer experience, there was a significant main effect, which is non-clients showed significantly more emotional arousal than clients across all ads ((***) F(1,1599) = 4.73, $p = 0.03$).

The EDA results according to participant gender are shown in Fig. 3. For main interactions, there was a significant interaction between advertisement type and gender (F(2,1593) = 3.28, $p = 0.038$), and between customer experience and gender (F(1,1593) = 25.28, $p < 0.01$). There was not a significant interaction between advertisement type, customer experience, and gender (F(2,1593) = 2.31, $p = 0.09$). As seen in Fig. 3a, across all ads, males show more emotional arousal than females ((+) F(1,1593) = 154.36, $p < 0.01$). When we examine the participant experience within each gender group, post hoc

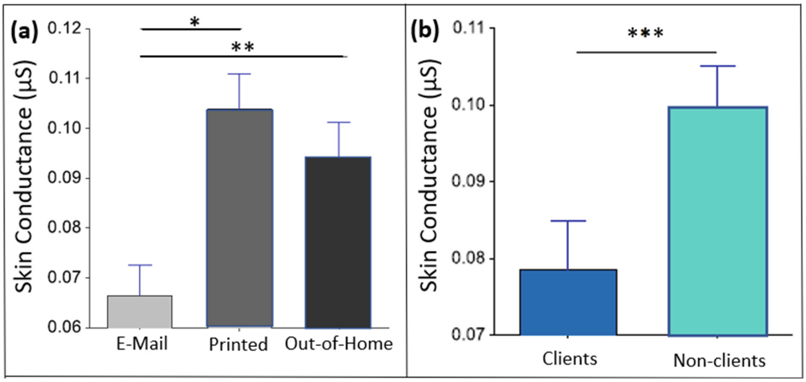

Fig. 2. (a) Skin conductance levels according to the advertisement type. (b) Skin conductance levels according to the participant experience. (c) Skin conductance levels according to the customer experience over each advertisement type. Whiskers are SEM. Significant contrasts are marked over the bars.

results indicate male clients show more emotional arousal than male non-clients ((++) F(1,1593) = 8.19, $p < 0.01$), and female clients have significantly less emotional arousal levels than females that are not clients ((+++) F(1,1593) = 20.88, $p < 0.01$) (Fig. 3b). Shown in Fig. 3c, male clients are significantly more emotional aroused in e-mail ((*) F(1,398) = 7.82, $p < 0.01$), and printed media ads ((***) F(1,642) = 4.94, $p = 0.027$), while female clients are less aroused by both e-mail ((**) F(1,398) = 5.61, $p = 0.018$) and printed media ads ((****) F(1,642) = 19.74, $p < 0.01$). Out-of-house ads did not show any significant differences.

In the context of participant age, the EDA results are as shown in Fig. 4. For equal distribution over each age group, we defined two groups, those who are under the age of 42 (mean age rounded up) as 'younger' participants and those who are over 42 as 'older' participants. For main interactions, there was a significant interaction between advertisement type and participant age (F(2,1593) = 4.09, $p = 0.016$), the interaction between customer experience and participant age was not significant (F(1,1593) = 3.659, $p = 0.054$). Also, there was no significant interaction between age, experience, and advertisement type (F(2,1593) = 2.03, $p = 0.13$). As seen in Fig. 4a, across all ads younger group had more emotional arousal levels than the older group ((*) F(1,1601) = 22.29, $p < 0.01$). Shown in Fig. 4b, post hoc results indicate that the trend in Fig. 4a continued regardless of being a client ((*) F(1,1601) = 21.99, $p < 0.01$) or a non-client ((**) F(1,1601) = 4.56, $p = 0.03$), and older clients showed significantly more arousal than older non-clients ((***) F(1,1601) = 4.22, $p = 0.04$). Shown in Fig. 4c, older clients ((*) F(1,398) = 6.62, $p = 0.01$) and younger non-clients ((**) F(1,398) = 6.69, $p = 0.01$) are significantly more aroused in e-mail than older non-clients. Also, in printed media ads, younger clients show more arousal than their older counterparts regardless of being a client ((+) F(1,642) = 10.99, $p = 0.001$) or a non-client ((++) F(1,642) = 9.50, $p = 0.002$). Like in gender factor, out-of-house ads did not show any significant differences in age groups.

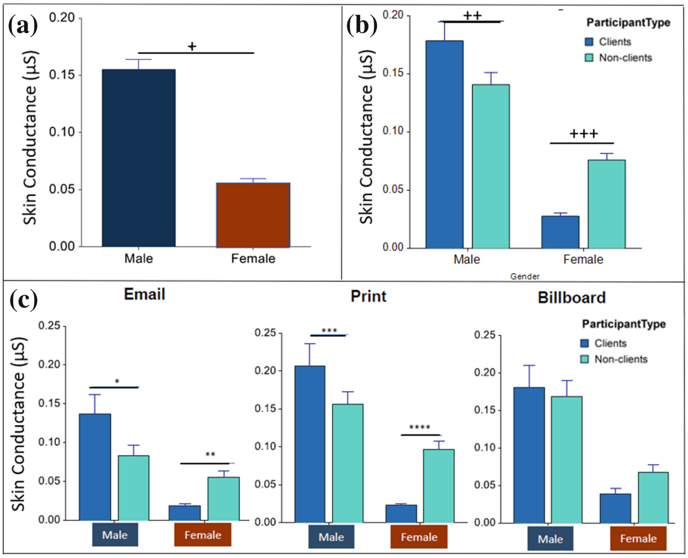

Fig. 3. Skin conductance levels across all advertisements according to gender (a), participant experience in each gender (b), and gender and customer experience over each advertisement type (c). Whiskers are SEM. Significant contrasts are marked over the bars.

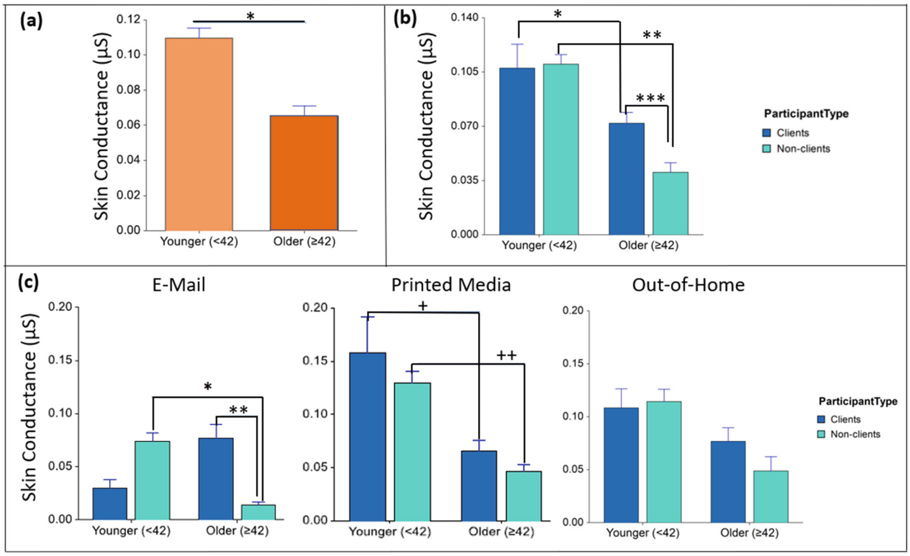

Fig. 4. (a) Skin conductance levels across all advertisements according to age. (b) Skin conductance according to participant experience in each age group. (c) Skin conductance over each advertisement group in each age and consumer experience group. Whiskers are SEM. Significant contrasts are marked over the bars.

4 Discussion

In this study, our goal was to evaluate the effects of viewing e-mail, printed media, and out-of-house advertisement on consumers' emotional arousal by using EDA, a sensor that measures skin electrical properties to track correlates of autonomic nervous system activity [11]. We have investigated the skin conductance levels while the participants were observing the advertisements and we compared the effects of advertisements in terms of their type, alongside participant gender, age, and experience as a customer. Our EDA results indicate that the e-mails were the least stimulating advertisement type to customers. This might be because in e-mail environments alongside legit advertisements, there is also a lot of spam frequently, which could make customers less attentive and more critical towards e-mail advertisements in general [22]. Also, non-clients showed more emotional arousal than clients in general. This might be explained as non-clients being more judgmental in reviewing advertisements due to covering the lack of experience, while clients are more familiar with the advertisements shown, hence not doing much processing towards the advertisements. In the context of gender, males engaged more with advertisements in general. In terms of consumer experience in each gender, female clients showed less stimulation in e-mail and printed ads, while male clients showed more emotional arousal in the same advertisements. In terms of participant age, we see that younger people were more emotionally engaged from the ads than the older participants. Furthermore, from the behavioral perceived affinity questionnaires, we can see that young non-clients tend to like advertisements less than other groups. This might be due to younger non-clients being critical in observing advertisements, which is also seen in EDA results in terms of both customer experience and age, resulting in lower perceived affinity scores. Also when we examine advertisement types, we see that older clients show more emotional arousal to e-mails. This might be because as mentioned above, younger clients might be more critical to e-mail ads due to the abusive use of spam advertisements in e-mail advertising [23].

There are a few limitations to this study. The first limitation is that we only looked at law-firm advertisements, and different brands/contexts could have a different impact on the factors investigated here. The second limitation is that we have looked at only a limited medium of advertisement delivery, specifically billboards, e-mail, and print media ads. There are other advertisement types/mediums such as TV commercials, digital advertisements, and mobile advertisements, that could be investigated in other studies.

In conclusion, we used EDA to assess the impact of advertising and advertisement characteristics on consumer behavior in terms of emotional arousal and perceived affinity in this study. The findings show that advertisement type seems to have a different impact on customers regarding their gender, age, and customer experience. In advertisement types, we see that e-mail ads were the least engaging to all participants. In the context of customer experience, non-clients were more emotionally engaged than clients, specifically in printed media ads. In terms of age, younger participants tend to engage more than older participants, while showing less affinity. Also, older clients engaged more with e-mails, while younger clients engaged more in printed media ads. Albeit the limitations, this study is a promising step towards demonstrating EDA as a supportive tool to provide valuable information about consumers' emotional arousal while advertisement viewing, which can be beneficial in understanding consumer behavior in social studies. Extending the understanding of the relationship between advertisements and consumer behavior can help advertisers optimize ad development and delivery.

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Systemic-Structural Activity Theory

Systemic-Structural Activity Theory and Artificial Intelligence

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Abstract. This paper is dedicated to the analysis of the issues the Artificial Intelligence (AI) developers are facing when they design the software. We suggest to use the numerous Systemic-Structural Activity Theory (SSAT) methods of analyzing and optimizing human performance in order to streamline the AI design process. The paper offers examples of the AI applications and describes some of the methods and application of the SSAT framework. AI replaces routine human tasks with the software and SSAT methodology allows to analyze human performance and build the human algorithm that can be replaced by AI. Utilization of SSAT will make software development much more efficient.

Keywords: Artificial Intelligence (AI) · Systemic-Structural Activity Theory (SSAT) · Task analysis · Safety · Efficiency

1 Introduction

The evolution of automation and the current evolution of artificial intelligence are accompanied by the constant progress in human factors/ergonomics. Table 1 presents the evolution of the automation. Increasing machine intelligence leads to a shift from a mere interactive to a much more complex cooperative human-machine relation requiring a multidisciplinary development approach.

Let us briefly consider the most resent applications of AI.

Quick, creative, and convenient customer service is a must for all companies. Sixty three percent of customers will leave a company website after just one poor experience, and almost two-thirds will not wait for more than two minutes for assistance and unsatisfied users rarely ever equate to repeat users. The impatient user is a relatively new phenomena that affects all areas of the service industry.

AI systems are employed to achieve such goals as improvement of UX (user experience) and replacement of the repetitive processes in order to increase productivity to name just a few. The improvement in user experience often arises from providing particular value such as for example, reducing the number of abandoned actions for the most commonly used searches on the Websites [1].

There are a range of methods and tools utilized in the AI software design such as Figma, Adobe XD, Webflow, Sketch, UX Pin, Invision studio, etc. A lot of authors suggest just to follow the users' steps when designing the AI software.

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Table 1. Evolution of automation.

Desktop automation	Robotic process automation	Cognitive automation		Artificial automation	Fully automated
Improved workflow	Optimized process through automation	Statistical logic automation	Pater based machine learning	Self-learning and application	
Scripting of individual tasks Assists stuff with their activities Runs on each agent's desktop Increases efficiency of workers Helps to consolidate information and provide consistent customer experience Assists in streamlining work and optimizing processes	Large scale unattended processing Must respond to fluctuation in system response, unknown events, unanticipated business scenarios without interruption Considers security, scheduling, exception management Centralized collection of management information, audit records and process logs	Aids or replaces subjective decision making based on large data samples Interprets contextual information and provides consistent reasoning Assists in the streaming of processes and routing of enquiries Allows human-like reasoning to be applied in large volumes, transactions monitoring, fraud identification, call filtering		Robotic process automation (RPA) - use of software with artificial intelligence (AI) and machine learning capabilities to handle high-volume, repeatable tasks that previously required human performance Queries, calculations and maintenance of records and transactions	

The designers are usually left with the only option to create the prototype and let the QA or the end users to test it. Such strategy is very costly and leads to the numerous iterations of the software design, development and testing.

The Human-Machine Task Integration studies clearly imply that Human Factors and AI research are thoroughly intertwined into the human-machine cooperation system design process [2].

This paper suggests to utilize the SSAT methods in the development of AI apps and interfaces and offers an insight into the quantitative methods of evaluation of AI systems' efficiency by applying the SSAT framework [3]. This high-level generality theory offers methods that allow to evaluate the quality of the software design at the initial stages of its development.

2 Various Applications of Artificial Intelligence

In our latest paper [4] we describe the case study of the BOT (Build-Operate-Transfer) development and discuss the shortcomings of the collection of information from the users, that has been utilized there.

Our most recent case study describes development of the BOT. This BOT was intended to replace verification of financial reports. One of the functions of this BOT is to send an email with the results of this process. This accounting function is performed constantly and repetitively. So the decision was made to create the BOT that would perform this function. The developers used the questionnaire, the fragment of which we present in Table 2. The analysis of the gathered information demonstrated that different operators used different strategies to perform the same task and the BOT designers had no tools to identify the best sequence of steps to perform this task. We argue that SSAT is the best tool to identify the most efficient and safe method of task performance.

In everyday life, people make decisions and solve problems. Most of the decisions that people make are done quickly, because this method does not create any problems for them. Problems come with difficult decisions, when the decision-maker cannot differentiate among available alternatives and/or the best alternative does not have a sufficient level of motivation for its execution. Though, the decisions concerning the healthcare are often rather difficult to make.

Table 2. Fragment of the questionnaire.

Current process overview	
1	Describe the current process:
1.1	Document the step-by-step procedure of the current process:
1.2	Are there manual checkpoints and/or approvals within the current process?
Applications accessed	
2	Identify all of the applications, websites, servers, that are accessed:

User access	
3	Identify the ID and access for the applications, websites, servers, that are accessed:
	--
Error handling	
5	Identify error handling:
5.1	Identify common issues and errors in performance of the current process:
	-- ------------------------------------

Let us consider the application of AI in the healthcare system. There are obvious potential health and economic benefits that the widespread adoption of AI can bring. Examples of the use of AI in healthcare include machine learning algorithms that rely on pattern recognition, classification and prediction.

For example, deep learning is particularly well suited to the interpretation of radiological images because of the complexity and richness of the data [5].

The sergeants are complaining about the lack of the step-by-step instructions for the complicated and very time-consuming surgeries and state that the AI system that would keep track of the steps would be extremely helpful.

A very interesting paper on this subject has been published by the scientists at the University of York [6]. The authors considered a number of the studies dedicated to the various application of AI to the healthcare. They noticed that the focus of the evaluation is usually on the performance of the AI on a narrowly defined task. The evaluation is typically undertaken by the developers, and independent evaluation remains the exception.

According to the AI developers' evaluation studies of such AI algorithms have produced encouraging results. The evaluation of a bedside computer vision algorithm to identify and monitor behaviors of doctors, such as hand washing, suggests that the algorithm can achieve 95% accuracy. Skin cancer detection using algorithms might outperform dermatologists at this task. Similarly, the developers of the AI system that detects diabetic retinopathy found their algorithm achieved over 95% accuracy. For the management of sepsis, the evaluation carried out by the developers of an algorithm trained by reinforcement learning found that on average patient mortality was lower when doctors' management decisions matched those suggested by the AI system.

However, there were some safety issues. For example, the evaluation of AI sepsis management has been criticized because the algorithm seemingly "learned" not to treat very ill patients which is hardly suitable in a real clinical environment.

In general, the sample sizes are often small, and the prospective trials are infrequent. As a result, the evidence base to date about the actual performance of AI in real-world settings remains weak.

The safety concerns in regards to application of AI in the healthcare system are also considered in the other paper [7].

A key argument for the safety of autonomous vehicles is that the driver is able to take control in case of emergencies or unforeseen situations. Research has put into question whether such an assumption is realistic in the first place, considering the short reaction time available [8]. Handover is also a well-recognized safety critical task in the delivery of patient care. Handover between teams of doctors and nurses turned out be a critical issue during the COVID-19 crises. The overworked teams of healthcare providers needed help in keeping track of the test results, consolidation of prescribed medications, etc.

In the future, handover between humans and autonomous AI systems will become increasingly important. The AI system needs to recognize the need to handover. While this might be achievable, the AI also needs to figure out what to hand over, how this should be done and when. In human handover, there is a need for structured communication protocols to convey clearly the salient features of a situation, for example, age, time, mechanism, injuries, signs, treatments [7].

Such critical issues as maximum allowed time for a patient to be on the ventilator or a medication, the conflict between the medications prescribed by different specialists can be handled by AI systems making sure that the handover of the patient care between the medical teams is successful.

The last paper dedicated to the healthcare we would like to consider here is called "Artificial Intelligence–Powered Smartphone App to Facilitate Medication Adherence" [9].

The authors point out that a lot of patients cannot identify pivotal warnings from the guides on the use of medications, as evidenced by an increase in all medication-related hospitalizations by 117% from 1997 to 2008. This is an alarming tendency.

The authors suggest to use a human factors-based methodology to iteratively design the application from the functional requirements by utilizing the user-centered design principles. They propose to use the usability inquiry approach for the iterative design to understand the users' likes, dislikes and needs. The multidisciplinary research team (including 20 clinicians with diverse clinical backgrounds and 12 researchers) iteratively reviewed and revised the app based on the written and verbal feedback related to the usability (think-aloud methods), efficiency and ease of use for four months or until no further revisions were identified.

The authors claimed that this study will lead the future of innovative AI-powered smartphone app design and act as the aid to improve medication risk comprehension, which may ultimately improve medication adherence. The results from this study should also open up future research opportunities to understand how patients manage complex medication information and inform the format and design for innovative AI-powered digital interfaces for medication guide. It's an interesting study but the suggested methods sound very time consuming and repetitive in nature.

It's not a coincident that the above-mentioned papers and a number of others are dedicated to the healthcare considering the COVID-19 crises we as a society are going through.

AI has been widely utilized in the fight against this virus [4].

Paper published in the Proceedings of the 2005 International Conference on Artificial Intelligence [2] considers a number of AI systems' design methods developed in cooperation with human factors specialists. One of them is a generic multidisciplinary cognitive engineering method CE+ for the integration of human factors and artificial intelligence in the development of human-machine cooperation. The paper covers a number of case studies but does not offer an integrated method of analyzing the task at hand and the goal of the user or application.

SSAT provides integrated methods that offer great potential for improvement of the quality of the AI systems.

3 Application of SSAT to Artificial Intelligence

Systemic-Structural Activity Theory has been presented in numerus books and articles. We are going to talk about the most recent book [3] where we are describing in great details the theory and methods that can be utilized for analysis and design of task performance. SSAT offers a unique opportunity to create the time structure of the task performance. This method is universal and can be used for the tasks that are purely human, AI or human-computer or human-machine tasks.

Figure 1 shows an example of one of the SSAT methods, namely the event-tree with.

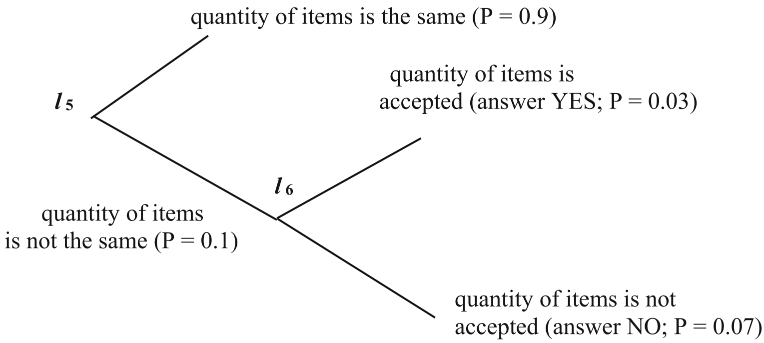

Fig. 1. Event-tree of decisions l 5 and l 6 when item quantity is evaluated.

The absolute probabilities of the events. l 5 and l 6 depict events that have two outcomes. This method allows to determine the probability of the successful task performance.

Creating such a time structure accompanied by event-trees facilitates determining the optimal version of task performance, evaluation of task complexity, avoidance of numerous abandoned actions [1], comparison of different version of the software [10].

Proposed by SSAT complexity measures are calculated using the activity time structure and the algorithm of the task performance. Comparison of different versions of the task performance by creating the algorithms and determining the task complexity allows to choose the best version of the task performance [4].

The proposed approach pays special attention to the reduction of errors and the reliability of the task performance.

Application of SSAT to the development of AI systems will make such systems more efficient and safer.

4 Conclusion

AI technologies undoubtedly bring the great potential in improving the UX and reducing the highly repetitive human task performance.

Though, attention should be paid not only to the development of AI technologies, but also to their rigorous evaluation. Human factors specialists should work hand-in-hand with AI systems' developers.

For example, in Healthcare industry it should be ensured that the impact of AI on patient care and patient safety, and potential hazards and human factors challenges can be addressed from the outset.

The suggestion to AI developers to "Do your research and ultimately make the best choice for your users" is not very helpful.

Increasing application of AI leads to a much more complex cooperative human-machine relation. This requires a multidisciplinary approach. This paper stresses the need of utilizing SSAT in human- machine cooperation system design. SSAT offers methods that allow significant improvement in human-machine cooperation. This can be done by deriving artificial intelligence design from studying and building the task time structure and analysis of its complexity.

Due to the complexity of system design processes, their success depends upon integration of human factors and artificial intelligence research early on in the development process.

This paper offers an insight into the quantitative methods of evaluation of the efficiency of the innovations suggested within the framework of SSAT.

Deep understanding of the problems of innovativeness demonstrates not only what has to be done, but also an explanation of why it is worth doing.

SSAT pays special attention to the psychological aspects of the task analysis, the complexity of the task, reliability of its performance, evaluation of innovations and development of efficient strategies of the task performance.

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Applying Web-based Application *ExpressDecision2* in Patient-Centered Care

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Abstract. *ExpressDecision2*® *(ED*$^{2®}$*)* is a web app designed to support the individual in quickly making difficult decisions under uncertainty, which are emotionally driven and typically solved by using rational intuition. *ED*^{2} is based on the self-regulation model of the thinking process developed within the framework of the systemic-structural activity theory. *ED*^{2} supports both decision-making and problem-solving processes. For problem-solving, *ED*^{2} supports goal-setting by implementing the principle of instrumental rationality. Paper demonstrates of *ED*^{2}'s application in making a patient-centered and shared-with-doctor decision about the best treatment option for cholesterol reduction.

Keywords: Web application · Decision-making and problem-solving · Self-regulation · Patient-centered care · Shared-with-doctor decisions · Cholesterol reduction

1 Introduction

The problem of reducing high cholesterol levels is typically solved by taking statins – this is what many patients' doctors tend to recommend. This recommendation is a purely problem-centered decision that doctors conventionally suggest because they are trained to do so. When patients voice their concerns regarding the fact that statins may negatively affect their muscles, fitness levels and liver, most healthcare professionals generally tell them that it is their (patient's) responsibility to weigh all the risks and make a decision accordingly. In reality, this is a trade-off between two risks: either the risk of having a heart attack or stroke while avoiding taking statins, or the risk of experiencing liver and other side effects while using statins to reduce high cholesterol levels. Typically, making the right decision becomes a difficult problem. When evaluating how practitioners and patients make medical decisions, we see that they traditionally use information models with greedy optimization (such as expected utility maximization, Bayesian inference, or logistic regression) when making diagnostic or treatment decisions. This is *problem-centered care* focused on the proximal or short-term goal (such as cholesterol reduction), which leads to over-testing and/or overtreatment, or under-testing and/or under-treatment

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of patients [1]. Because healthcare in general aims towards *patient-centered care* [2], each patient's proximal goal should be viewed from the perspective of attaining their distal or long-term goal to provide the best care possible. In this paper, we demonstrate *ED*^{2}'s application in making a patient-centered and shared-with-doctor decision regarding the best treatment option for cholesterol reduction.

2 Problem-Centered and User-Centered Decisions

According to H. Simon [3], *decision-making* is considered a process of evaluating and choosing from among alternative actions, whereas *problem-solving* is considered a process of choosing issues that require attention, setting goals, and finding or designing suitable courses of action.

Decision-making is typically *problem-centered* and is considered successful when the best action to reach the proximal goal is chosen, whereas problem-solving is *user-centered* and is considered successful when the best action for reaching the proximal goal is chosen from the perspective of the distal or long-term goal. This is why problem-solving provides *a more accurate solution* for the problem than can be achieved by decision-making. At the same time, problem-solving requires goal verbalization; this makes it less efficient than decision-making, when the goal is uncertain, as well as when the time required for its recognition and verbalization is an issue [4].

We consider a patient-centered decision to be a decision that the patient makes to reach their personal goals, whereas a problem-centered decision is a decision that solves the problem. A problem-centered decision becomes a patient-centered decision when the problem shares the same goal as the patient.

When making decisions, *instrumental or processing rationality* of the thinking process focuses on dividing the problem more efficiently into sub-problems in order to simplify the process of reaching the goal. This rationality is *bounded* due to limits in people's thinking capacity, available information, and time [5]. The main criterion to determine whether care provided by a health professional is truly "patient-centered" lies in verifying whether the *principle of instrumental rationality* in reaching the goal is satisfied: "the goal of each sub-problem must be a sub-goal in order to rationally attain the long-term goal" [6].

Shared decision-making (SDM), as opposed to clinicians making problem-centered decisions on behalf of patients, is gaining increasing prominence in healthcare policy. In shared decision-making, the health professional provides the patient with information about treatment options, clarifies these options, and answers the patient's questions [7]. The idea of SDM draws on and deepens the principles of patient-centered care [7]. At its core, SDM rests on accepting that individual *self-determination* is a *desirable goal,* and that clinicians need to support patients in achieving this goal, wherever feasible. SDM relies on the use of *decision aids* to assist the patient in selecting the best treatment option. Existing decision aids (such as the Diabetes Medication Aid, Osteoporosis Aid, and Statin Choice Aid) are *problem-centered*. Only by being implemented with the assistance of a health professional do they become *patient-centered*.

3 *ExpressDecision2*

ExpressDecision2® *(ED*[2]® *)* (https://expressdecision2.com) is a web-based mobile application designed to support individuals in making difficult decisions (which are typically solved intuitively) under uncertainty and time pressure. *ED*[2] implements the Performance Evaluation Process (PEP), which uses the self-regulation model of decision-making activity [6]. This makes *ED*[2] *behaviorally comparable* to the user, which increases decision advice acceptance. *ED*[2] can be used both for everyday and for professional decisions, and can be run on both desktop and mobile platforms, including smartphones. PEP implements two concurrently and dynamically running processes: formation of the mental model (FMM) and formation of the level of motivation (FLM) by using two main regulators: *factor of significance* (subjective importance) and *factor of difficulty* (subjective complexity). The factor of significance provides feedforward control, and the factor of difficulty provides feedback control. FMM uses eight instrumental *information*- and *energy*-based performance-shaping factors (PSFs) [8] to construct a decision tree, whereas FLM uses four instrumental criteria of success to evaluate alternatives' *pros* and *cons* with the help of *IL-Frame*. IL-Frame uses verbal characteristics to measure the intensity and likelihood of outcomes on the verbal scales "weak – strong" and "seldom – often," respectively. This soft evaluation of outcomes enables better interpretation of an uncertain goal and conditions while improving decision accuracy [9]. PEP includes the following three stages: decomposing the problem, evaluating alternatives with IL-Frame (uses psychologically determined rules of aggregation), and making a decision. *ED*[2] provides the user with two options: decision-making and problem-solving.

The *decision-making* option helps make quick decisions on the fly, but this decision has a low level of instrumental rationality (accuracy). The decision is *problem-centered* and targeted to reach the *proximate* or *short-term goal*. For example, to save a patient's life, emergency physicians must decide rapidly whether a patient is at "high risk" for having a heart attack and thus needs to be sent to the "coronary care unit," or if they are at "low risk" and thus only need to be sent to a "regular nursing bed."

The *problem-solving option* requires setting goals and recognizing problems. Here, arriving at the decision (solution) is not as rapid as in decision-making, but its level of instrumental rationality (accuracy) is higher because it is supported in applying the *principle of instrumental rationality*. The decision (solution) is *user-centered* and targeted to reach the proximate goal from the perspective of the distal or long-term goal. For instance, the solution for reducing high cholesterol (short-term goal) by taking either low, high, or no dose of statins is made from the perspective of "high quality of life," which serves as the long-term-goal.

The diagram in Fig. 1 demonstrates how *ED*[2] supports each of these options by checking for "low motivation" (undesirable choice), "high proximity" (inaccurate choice), and "time constraints" (time-consuming choice).

4 Applying *ED*[2] to Reduce High Cholesterol Levels

With the help of modern statin medications, the problem of reducing high cholesterol is not a difficult one. By using a high dose of statins, the patient can obtain a problem-centered solution to their "high cholesterol" problem. The more statins the patient uses, the lower the level of cholesterol in their blood will be, and as a result, they will lower their risk of heart attack and stroke.

Below is a hypothetical example of *ED*^{2}'s application in making a decision shared with the doctor, which relies on using the *Statin Choice Decision Aid* (https://statindecisionaid.mayoclinic.org/), an electronic tool designed to help select the best treatment option for cholesterol reduction.

John's Case

John, who is a relatively healthy 67-year-old man, visited his physician for a checkup regarding his blood work report, which indicated that his cholesterol level is high at 280. John has no chronic diseases, leads an active lifestyle and enjoys traveling and participating in sports. At his first appointment, John's doctor recommends that he begin using statins at either a standard or high dose to lower his high cholesterol, but suggests he first try a standard dose of statins. His doctor also explains the risk of taking statins: although statins can help lower John's cholesterol and thus reduce his risk for heart attack and stroke, they come with a number of side effects, some of which may hinder John's active lifestyle. In other words, there would be some trade-offs. By the end of this first appointment, John has learned about the general pros and cons of taking statins. He realizes that statins may adversely affect his muscles, physical endurance and overall exercise capacity, which would be a major blow to his athletic lifestyle, since he goes to the gym regularly and trains for several triathlons per year. Noticing John's uncertainty regarding taking statins, his doctor recommends that he do the following: (a) evaluate his risk of heart attack and stroke when considering different doses of statins with the help of Statin Choice Decision Aid; then (b) use ED2 with this information, along with the information obtained from his doctor (about statin side effects and the beneficial effects of a healthy lifestyle), in order to make a patient-centered decision regarding the most appropriate dose of statins he should take.

4.1 Statin Choice Decision Aid Applied to John's Case

John answered the following 10 questions: 1. History of cardiovascular events – *no.* 2. Age – *67*. 3. Gender – *M*. 4. Population group**–** *white or other*. 5. Smoker – *no.* 6. Diabetes – *no***.** 7. Treated SBP – *no.* 8. Systolic blood pressure (mmHg) – *125*. 9. HDL cholesterol (mg/dl) – *40* **(**reference interval: > 39). 10. Total cholesterol (mg/dl) – *280 (high)* **(**reference interval: 100 – 199). When John applied each of these available statin options to himself, he received the following results:

- Option 1. No statins: the patient's risk of heart attack or stroke is 19% ("19 of 100 people like you will have a heart attack or stroke (over 10 years)").
- Option 2. Std. dose of statins: the risk of heart attack or stroke is 14%.
- Option 3. High dose of statins: the risk of heart attack or stroke is 11%.

Statin Choice Decision Aid gave John a *problem-centered* solution for his "high cholesterol" problem: Option 3 "High dose of statins" is most effective for lowering high cholesterol, thus "reducing risk of heart attack and stroke".

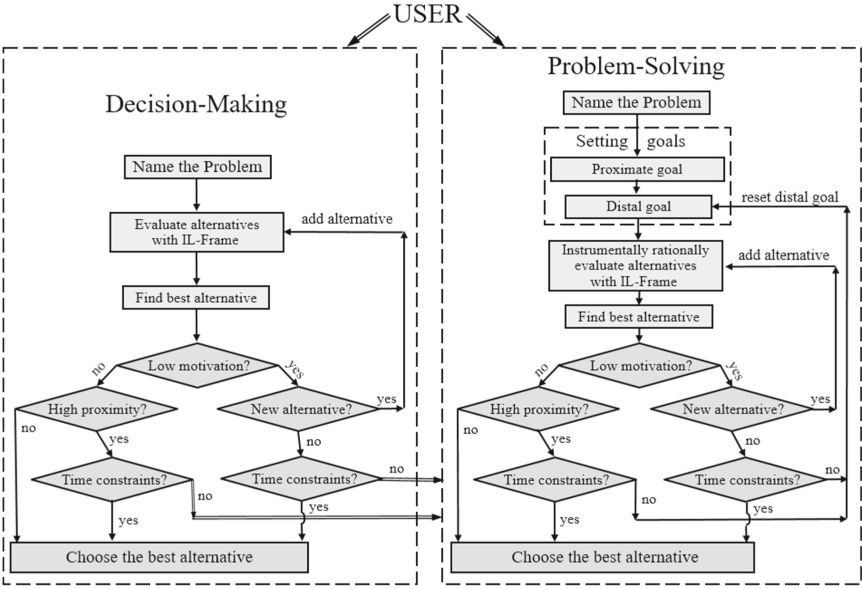

Fig. 1. Diagram for Decision-Making and Problem-Solving using *ED*^{2}

4.2 *ED*^{2} Applied to John's Case

ED^2 helps John make a motivated patient-centered decision regarding using statins based on information provided by his doctor, as well as analysis taken from the Statin Choice Decision Aid. *ED*^{2} provides two options: decision-making and problem-solving.

John started with the *decision-making* option as the quicker way to solve his problem, which gave him the following result: Std = 46%, High = 31%. Therefore, it appears that the Standard dose is the better option, although the level of motivation or preference for choosing this dose is still low (46%). This result only confirmed John's intuition: he was not even motivated to take the lower (standard) dose of statins.

ED^2 recommends he add a new alternative. John doesn't hesitate for a second, because the idea of statins and their side effects concerns him, and so he adds the option of "no statins." This alternative becomes the best one for John, but it still has a low level of preference (motivation) – 49% (+50%, −45%). *i.e.* 50% pros and 45% cons.

To make a motivated choice in these kinds of circumstances, *ED*^{2} recommends using the *problem-solving option* that operates with *goal-setting*, instead of the decision-making option that requires no goals to be made. Indeed, all the results obtained by *ED*^{2} align with John's intuitive aversion to taking statins, with the addition of rational reasoning thrown in. John assumes this happened because he does not understand his goals. In reality, he does not know what he actually wants more (to maintain his good shape or to avoid potential stroke and/or heart attack). In other words, his goals are very *uncertain* for him. Depending on his goal(s) and priorities, he can obtain different decision results. *Modifying a goal* consequently changes its value (what appears "good" with one goal may become bad with a different one). He knows that the main advantage of using ED^2 is the opportunity to play around with different goals while applying information and emotion factors. Applying the ED^2 problem-solving option makes the decision instrumentally rational, and this effectively leads to attaining the desired proximate and distal goals (even when the goals remains partially unconscious). ED^2 allows to more efficiently apply cognitive information (from environmental factors such as statistics, etc., as well as from internal factors, such as personal knowledge, experience, etc.) and energy factors, such as emotions, which can play a dominant role in decision-making. When using ED^2's problem-solving option, John needs to use the results he derived from the *Statin Choice Decision Aid* to evaluate his risk of getting a heart attack or stroke. John previously learned from his doctor about high cholesterol and its risks, as well as statins, their side effects, and how leading a healthy lifestyle may positively influence his condition.

One of the main advantages of using ED^2 is that it allows to compare all information and its emotional interpretations in such a way as to make a decision instrumentally rational (because ED^2 applies the *principle of instrumental rationality* in making decisions). Another advantage is that John is able to make a fast decision *before* arriving for a follow-up appointment with his doctor to further discuss his cholesterol management options. John decides to use the ED^2 problem-solving option with this *proximate goal*: *"reduce cholesterol < 200"* and *distal goal*: *"maintain active lifestyle."* This option for each alternative considers two hypothetical situations: one in which the chosen dose *helps* and the other one in which the chosen dose *doesn't help* lower John's cholesterol.

Section 4.3 demonstrates how ED^2 can help use the *Statin Choice Decision Aid* to apply the eight information- and energy-based PSFs and the four criteria of success (which are reflected by four verbal characteristics from the IL-Frame) to provide a *patient-centered* and *shared-with-doctor* evaluation of hypothesis "Std helps."

Taking no statins and instead applying some *alternate therapy/measures* (change lifestyle habits, improve diet, try other medication, etc.) seems to be the best option to try to reduce John's cholesterol while being able to maintain an active lifestyle. But with statins, the risk of getting a heart attack or stroke is lower than without them. Thus, the distal goal "maintain active lifestyle" does not help John make a clear decision: the "no statins" option is preferable, and he is motivated (53%) to choose it, but this alternative is very close to the option of taking a "standard dose of statins," which also has a sufficient level of preference (51%) to be chosen for execution.

However, based on his previous experience, John recognizes that reaching some of his long-term goals did not make him happier, because he underestimated some of the potential consequences that went along with them (an example from John's past: he worked hard to earn more money (distal goal). Although he managed to begin earning more than his colleagues, this hyper-focus on his work caused problems both with his health and family relationships. Thus, he begins thinking: maintaining his good shape and fitness levels makes sense to some extent, but values and priorities can shift dramatically with age. Additionally, John now recalls that his mother had died at 75 from a stroke, while his father already had his first heart attack at 70.

Therefore, John decides to apply ED^2 with an even *more distal goal* of "*high quality of life*" (instead of "*active lifestyle*"). This reframing of the problem by resetting the distal goal and making it more long-term helps him make a clearer decision — taking a standard dose of statins would be the better option (61% preference) for him from the perspective of maintaining a "*high quality of life while getting older*." Now, the option of no statins only has a 53% preference level, and John realizes that his best bet is to take a standard dose of statins to balance out his risk with his long-term quality of life as he gets older.

ED^2 allows John to weigh and compare all potential risks based on his own goals and preferences. Considering these risks and weighing their respective pros and cons through the lens of a shared-with-doctor decision-making approach can help John obtain the following conclusion: Option 2 "Standard dose of statins" is most effective for allowing John to *"maintain a high quality of life" while reducing his cholesterol level.*

Below are the main steps of *ED*^{2} application for getting a *patient-centered* solution for the John's "high cholesterol" problem, which was done in the span of 10 min.

1) Applying *ED2*'s *decision-making* option: "standard dose statins" (STD) vs "high dose statins" (HIGH). Conclusion: STD [46% (+64%, −73%)] is the better option, than HIGH [31% (+55%, −91%)] but John is not sufficiently (46%) motivated to choose STD. New alternative "no statins" (NO) is added.
2) Continue applying *ED2*'s *decision-making* option*:* STD vs HIGH vs NO. Conclusion: NO [49% (+50%, −45%)] is the best option, but John is still not sufficiently motivated (49%) to choose NO. He should consider *ED2*'s problem-solving option with setting a goal.
3) Applying *ED2*'s *problem-solving* option with *proximate* and *distal* goals: STD vs NO. Proximate goal: "Reduce chol < 200". Distal goal: "Maintain an active life style." Con-clusion: NO [53% (+50%, −41%)] is the better option, but its advantage over STD [51% (+55%, −50%)] is not obvious to John. He should reset his distal goal to make it even more long-term.
4) Continue applying *ED2*'s *problem-solving* option with the *reset distal goal*: STD vs NO. Proximate goal: "Reduce chol < 200." Distal goal: Maintain high quality of life while getting older." Conclusion: STD [61% (+57%, −34%)] is the better option, with a suffi-cient level of motivation (61%) for being selected, as well as a clear advantage over alternative NO [53% (+61%, −55%)].

4.3 Evaluating Hypothesis "STD Helps"

Because John wants to know whether the standard dose of statins will work for him, he evaluates Option 2 ("Standard dose of statins") by considering two hypothetical situations (sub-problems): "Standard dose helps" (reduces cholesterol below 200) and "Standard dose does not help" (level of cholesterol remains over 200).

John's doctor explains to him how managing to avoid a heart attack may affect his active lifestyle, as well as why a standard dose of statins can help him stay in the ranks of 86% of people who avoid having a heart attack if they take the standard dose of statins. Along with his personal values regarding taking a standard dose of statins (factor eS+), this information (factor iS+) leads John to select *"very strong"* in evaluating the significance of positive outcomes (S+) if "Std helps."

The fact that 86% do not have a heart attack when taking the standard dose of statins, combined with the fact that around 81% of people like John do not have a heart attack even without taking statins, indicates (iD+) that statins do not make such a substantial difference in risk reduction (the reduced risk is only 5% = 19%–14%). This leads John to make the personal and therefore energy (emotion)-based (eD+) decision to select *"seldom"* in evaluating the likelihood (D+) of obtaining *"very strong"* positive outcomes if taking the standard dose of statins. Based on both criteria S+ ("*very strong*") and D+ (*"seldom"*), *ED*^{2} determines that the level of *positive preference (pros)* for "Std helps" is at 59%.

John's doctor also elaborates on how statins may affect his liver and covers some basic approaches regarding how to reduce potential negative side effects. This information (iS-), along with John's personal evaluation of it (eS-), leads him to select *"not weak, not strong"* in evaluating the significance of negative outcomes (S-) in case "Std helps." Information provided by his doctor, coupled with statistics garnered from the *Statin Choice Decision Aid* regarding risk of heart attack when taking the standard dose of statins (19%) versus not taking any statins (14%), allows John to arrive at the following personal evaluation. Even though he evaluated the potential negative effect of statins on his liver as *"not weak, not strong,"* taking statins nonetheless does reduce the risk of heart attack from 19% (no statins) to 14% (standard dose); this means there is a 26% risk reduction. Considering all this, the likelihood of a negative effect on his liver is rated as *"not seldom, not often."* Based on both criteria S- (*"not weak, not strong"*) and D- (*"not seldom, not often"*), *ED*^{2} determines that the level of *negative preference (cons)* for "Std helps" is at 50%.

With John's primary goal being "*maintain an active lifestyle*," the evaluation of "Std helps" was undertaken with the goal of evaluating "*how a standard dose of statins helps John maintain an active lifestyle."* This goal serves as a sub-goal in reaching the "active lifestyle" goal. Therefore, the shared evaluation of "Std helps" is *patient-centered*, because it satisfies the principle of instrumental rationality. The goal of evaluating "Std helps" is a sub-goal that will help reach the distal goal*: "maintain an active lifestyle.*" This demonstrates how *ED*^{2} supports patients by providing a *patient-centered* and *shared-with-doctor* decision.

Figure 2 presents IL-Frame (decision tree) with the corresponding screenshot of *ED*^{2} for hypothetical situation "Standard dose helps."

The exact same process used in this example is also applied when evaluating the scenario in which the standard dose of statins does not help ("Std doesn't help"). The pros and cons of both these decisions are then aggregated to arrive at a final decision. However, if the patient has difficulty evaluating the outcomes of a hypothesis, he can explain these difficulties to his doctor, who can then assist the patient in further breaking down the problem into more specific sub-problems, in order to simplify the evaluation process until it is successfully completed. Furthermore, an analogous approach is to be used when trying to evaluate the pros and cons of a variety of scenarios related to this issue, including what particular *kind of statin* might work best for the patient.

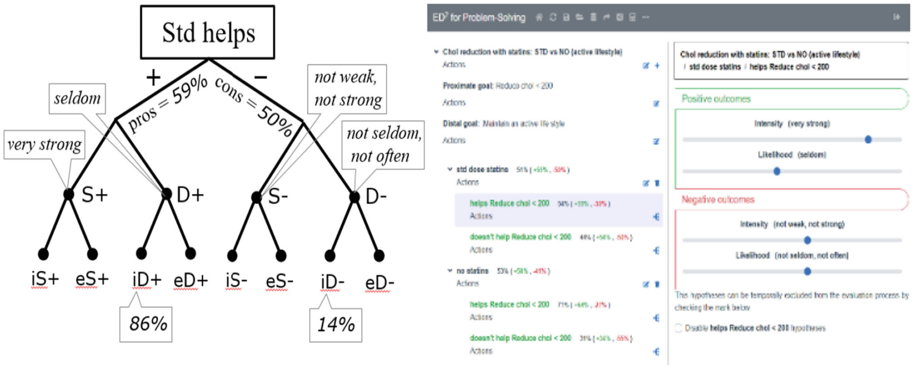

Fig. 2. IL-Frame (left) and the corresponding screenshot of *ED*^{2} (right) for hypothesis "Standard dose helps" with pros = 59% and cons = 50%.

5 Conclusion

The key objective was to apply the self-regulation model of decision-making under uncertainty and time pressure to build a mobile application that would be *behaviorally comparable* to its user, with the purpose of increasing advice acceptance. To accomplish this, we developed the *ED*^{2} web application that provides instrumental support in making *patient-centered* and *shared-with-doctor* decisions. *ED*^{2} enables *doctors* to share knowledge and information about treatment options (with the potential help of decision aids) to align with patients' goals. *ED*^{2} enables *patients* to more efficiently implement their thinking processes to make a reasonable decision regarding the best treatment option, all while factoring in their feelings and beliefs, as well as the information obtained from their doctor. Unlike existing decision-support systems, *ED*^{2} provides *user-centered* support that is *information-* and *energy (emotion)*-based, instead of information-based and problem-centered. It does not replace other tools and models, but rather functions to support them in a more effective and comprehensive way to render the decision user-centered and shared-with-expert when needed.

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Neurocognitive Indicators of Insight According to P300 and Later Visual ERP Components

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Abstract. Event-related potentials (ERP) traditionally on 42 healthy subjects (men) aged 20–28 years were recorded. The visual images were a line of visual images with an incomplete set of signs, as well as images-illusions, which, with different perceptions, represent different images. The article discusses the results of original research in the context of the discussion of modern studies of the well-known psychological phenomenon of P300 evoked potentials. Thus, the main trends in the change in ERP depending on the variants of recognition of visual illusions and oddball images are as follows. Complete recognition of illusions, which corresponded to insight in the model of our experiment, was accompanied by an increase in the amplitude of the P300 wave in the temporal-parietal regions on the right. With correct identification of one of the dual images, the activation of the N450 component was recorded in the frontal regions on both sides. Negative recognition was characterized by generalized symmetric activation of all ERP components, more pronounced in the posterior half of the brain.

Keywords: Consciousness · Event-related potentials · Wave P300 · Late components of ERPs · Oddball paradigm · Categorization of images · Images-illusions

1 Introduction

Research into insight as a psychological phenomenon began about 100 years ago, but neuroimaging and neurophysiological methods have been applied only in the last 20–30 years [1, 2]. There are a line of potential definitions of insight, depending on which combination of features is chosen, but rather on the research objectives – psychological, clinical, physiological, etc. [3, 4]. Often the definition is associated with a sudden solution to the problem, which was preceded by a dead end and re-structuring of the problem. This was followed by a positive emotional reaction. In cognitive psychology and cognitive neuroscience, there is a mismatch regarding what we consider to be the main criterion for insight, namely surprise. For example, in a line of studies on insight, the authors do not specifically highlight decisions that have arisen suddenly [5–7]. Another widespread use of the term “insight” can be found in clinical psychology, where insight refers

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to self-awareness, often personal symptoms, functional impairments, or other types of foresight. The clinical and unscientific use of the term does not require sudden awareness or any concomitant emotional response. Indeed, in clinical psychology, the absence of an emotional response can itself be viewed as a symptom indicating a lack of insight [8–10].

In particular, there is a definition of insight as any sudden understanding, awareness or solution of a problem, which includes reorganizing the elements of a person's mental representation of a stimulus, situation or event to obtain a non-obvious or non-dominant interpretation [10].

Recently, insight-related coarse semantic coding has been established in the right hemisphere and internally focused attention before and during problem solving. Individual differences in propensity to solve problems in a discerning, rather than conscious and analytical way are associated with different patterns of brain activity at rest. Direct brain stimulation has also recently begun to be used to facilitate insight. In short, the cognitive neurobiology of insight is an exciting new area of research related to fundamental neurocognitive processes [1, 11].

The paper discusses the results of original research in the context of the discussion of modern studies of the well-known psychological phenomenon of P_{300} visual evoked potentials (VEP). The objective of this study was to study the classification of insight for visual illusory images consisting of several objects simultaneously according to the analysis of early, middle, late, and ultra-late components (up to 1000.0 ms) of event-related potentials.

2 Methods

The research on 42 healthy subjects (men) aged 20–28 years was performed. ERP traditionally in 19 monopolar sites were recorded. Visual images for a short time (duration 0.3 ms, frequency 0.5 Hz, 30 savings) on the display screen were presented. The stimuli were a line of visual images with an incomplete set of signs, as well as images-illusions, which, with different perceptions, represent different images. Dual visual images-illusions with complete correct identification were a model of the phenomenon of insight. The recognition of one of the dual visual images, as well as the recognition of images with an incomplete set of features, presented a model of perception of oddball images. The lack of correct identification was considered as a common figurative stimulation. The quantitative characteristics of the answer options in the recognition of dual images-illusions and fragments of oddball images are presented in Table 1.

The P_{300} wave, as well as the later waves N_{450}, N_{750}, N_{900} ERPs in solving ergonomic problems, can be considered indicators of the categorization of the perception of visual illusions. Step-wise discriminant and factor analysis (BMDP Statistical Software) to establish the stability of ERPs parameters were applied. The amplitude relative to the isoline and the peak latency (PL) were measured. Differences were considered statistically significant when the value of the F-statistic of the stepwise discriminant analysis was more than 4 ($F > 4.0$). A stepwise discriminant analysis was carried out in comparison with the data of a control group of healthy subjects with VEP registration in response to an identifiable visual image.

3 Outcomes

Table 1. Quantitative characteristics of answer options in experiments with the presentation of dual images-illusions and correct identification of the oddball image

Answer options	Full identification	Identification of one image	Unrecognition	Oddball image identification
Number of responses	8	15	12	7

Later waves with full recognition of images-illusions change as follows (Table 2). The amplitude of N_{450} in the left occiput increases (F = 4.4), and the amplitude of N_{750} also increases in the occipital (F = 5.2) and central (F = 4.4) sites of the right hemisphere. The N_{900} parameters remain unchanged from the control data (F < 4.0).

Table 2. Amplitude (A, uV) and time (T, ms) characteristics of the component N350 ERP with full recognition of illusion-images and of the component N450 with unrecognition

Parameters	Sites	N350		N450	
		Control	Recognition illusions	Control	Unrecognition illusions
T A	O2	364.0 ± 59.3 2.8 ± 0.5	291.6 ± 47.8 * 5.3 ± 2.4 *	461.6 ± 42.7 3.0 ± 1.3	461.6 ± 42.7 5.0 ± 1.3 *
T A	O1	371.6 ± 59.3 2.7 ± 0.8	316.6 ± 46.6 * 4.1 ± 1.4 *	466.0 ± 37.9 2.9 ± 1.2	466.0 ± 37.9 4.9 ± 1.2 *
T A	C4	371.3 ± 57.1 2.9 ± 1.2	300.0 ± 68.8 * 4.5 ± 2.0	459.7 ± 42.0 3.8 ± 1.8	459.7 ± 42.0 5.8 ± 1.8 *
T A	C3	369.7 ± 56.0 2.9 ± 1.4	335.0 ± 27.2 3.7 ± 1.1	460.6 ± 40.8 4.0 ± 1.9	460.6 ± 40.8 5.0 ± 1.9 *
T A	F4	367.6 ± 64.6 3.0 ± 1.1	305.0 ± 77.3 4.6 ± 2.3	456.2 ± 42.2 4.2 ± 1.5	456.2 ± 42.2 6.2 ± 2.5 **
T A	F3	362.6 ± 65.5 3.2 ± 1.3	302.5 ± 78.5 4.6 ± 2.1	455.0 ± 44.3 4.5 ± 1.4	455.0 ± 44.3 6.5 ± 1.4 **

Notes. F-statistic value by compared to the control: * - F > 4.0, 2 * - F > 10.0; in other, the differences are insignificant - F < 4.0

With the correct detection of one of the dual objects, the PL P_{250} and N_{350} is shortened at almost all registration points (F > 4.0). The amplitude P_{250} increases in the central (F = 4.1) and frontal (F = 5.1) sites on the right, and N_{350} – in the left occiput (F = 4.2). In the absence of recognition, the PL and the P_{250} amplitude do not differ from the control ones (F < 4.0), and the N_{350} amplitude is reduced mainly in the anterior half of the brain (F > 4.0).

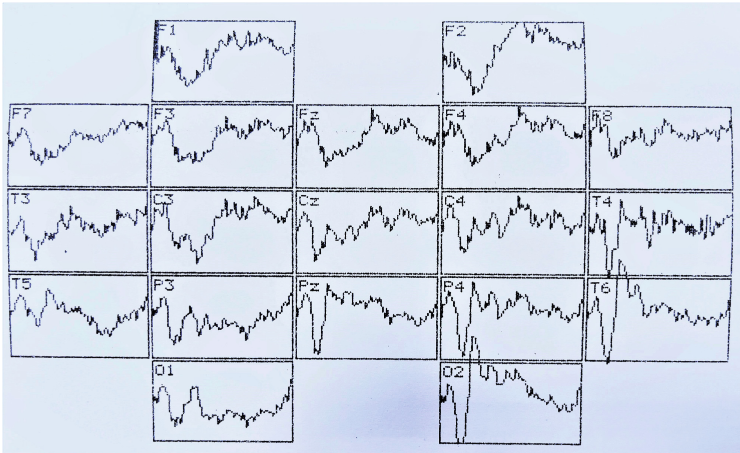

Fig. 1. VEP distribution by system 10/20 with correct recognition of images-illusions. Analysis epoch – 1000 ms.

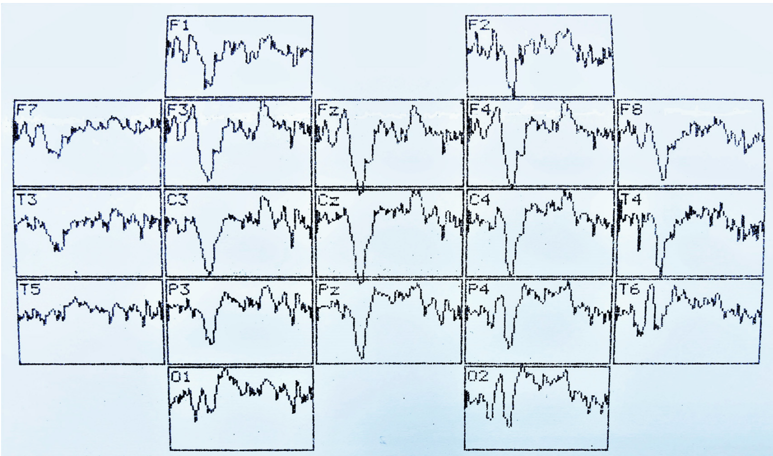

Fig. 2. VEP distribution by system 10/20 with correct recognition of one of the images-illusions. Analysis epoch - 1000 ms.

Correct detection of oddball patterns does not affect the parameters of the latest (N900) wave. At the same time, the N_{450} amplitude increases in the occipital cortex (F > 4.0), while the PL increases in the anterior regions (F > 4.0). The N_{750} amplitude does not differ from the control one (F < 4.0), but the PL is reduced throughout the cortex (F > 4.0).

Recognition of one of the dual images does not affect the characteristics of N_{450}, but in almost all sites the amplitude of N_{750} increases ($F > 4.0$) with a maximum in the right frontal cortex ($F = 17.3$). The amplitude of N_{900} increases only in the right occiput ($F = 4.8$) and frontal ($F = 7.5$), as well as in sites C_3 ($F = 9.2$) and F_3 ($F = 6.3$).

Unrecognition (Table 2) upon presentation of dual images-illusions, the amplitude of N_{450} increases in a generalized manner ($F > 4.0$), and the amplitude of N_{750} and N_{900} increases in all leads ($F > 4.0$), except for the occipital registration points ($F < 4.0$).

Figures summarize the main statistical findings. A particular typical example of the spatial distribution of VEP is presented with the correct recognition of dual images-illusions (Fig. 1). There is a reduction in evoked activity (especially at the early and intermediate stages of information processing) in the frontal and central regions of the brain, as well as an increase in the amplitude of the N_{350} wave in the temporal-parietal regions of the right hemisphere (O_2, P_4, T_6). Figure 2 reflects a typical example of the VEP spatial distribution in the case of identifying one of the dual figures - the oddball image variant. There is an activation of the frontal cortex (F_3, Fz, F_4), as well as a well-pronounced component N_{450}, by analogy with the variants of the lack of recognition and activation of short-term visual memory. The lack of recognition of visual images is characterized by generalized symmetric activation throughout the entire epoch of analysis, more pronounced in the posterior half of the brain (Fig. 3).

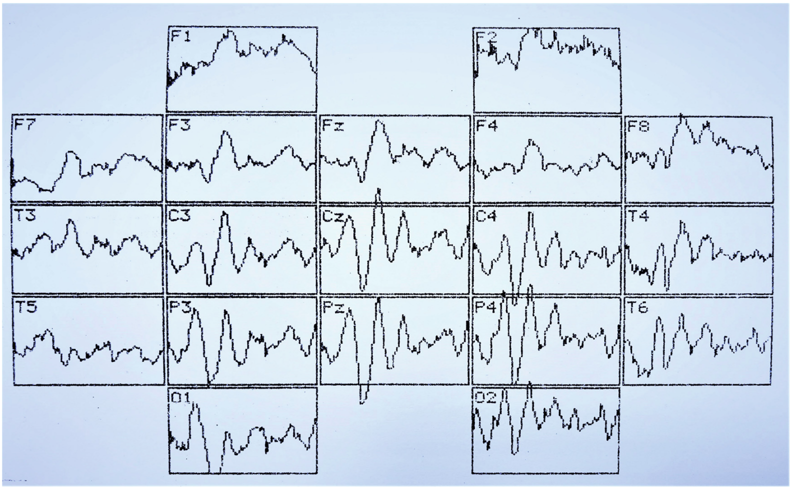

Fig. 3. VEP distribution by system 10/20 with unrecognition of images-illusions. Analysis epoch – 1000 ms.

4 Discussion

Neuroimaging studies of insight are carried out mainly based on EEG data. Other methods of brain research are less common [1, 12]. The EEG is considered to have high temporal resolution with limited spatial resolution. fMRI, on the other hand, has excellent spatial resolution with limited temporal resolution, so it is better suited for localizing a neural event in space. Together, these methods were able to isolate neural correlates of insight in both space and time. The combination of techniques was critical because fMRI's ability to localize insight-related neural activity would be less informative if it were not for knowing whether these neural correlates arose before, after, or at the time of decision [8].

When the problem is solved intuitively, EEG shows a burst of high frequency EEG gamma activity over the right temporal lobe, and fMRI shows a corresponding change in blood flow in the right anterior superior temporal gyrus [8]. In the original fMRI experiment, this right temporal region was the only area that exceeded the statistical thresholds. Further, weak activity was found in the hippocampus and parahippocampal gyri, as well as in the anterior and posterior cingulate cortex. In a later study the same network of regions far exceeded the critical statistical threshold, with the right anterior temporal region again being the strongest [4].

The results of the present study on ERP registration data show the similarity of the tests with the correct recognition of fragments of glasses and dual images. At the intermediate stage of perception (100–200 ms), in both cases, the activity of the central and frontal cortex decreases, mainly in the left hemisphere. At the later stages of information processing (300–500 ms), the temporal-parietal and occipital parts of the brain on the right are activated, with the difference that when dual objects are perceived, this process is extended to 700–800 ms with the activation of the central and occipital fields of the right hemisphere.

Other electrophysiological data [13] suggest that even from two opposite ERP results, it is possible to trace the features of internal and external insight. Internal insight is associated with positive ERP components after stimulus onset (P200–600) above the superior temporal gyrus [14]. External insight is associated with a negative component of ERP (N320) [15]. These results already show that external and internal insight differ at the behavioral and neurophysiological levels. various neurobiological insights suggest that presenting a solution or a decision clue leads to the same "aha" moment as attempting an inner decision [5, 16–19].

The spatial and temporal consistency of fMRI and EEG results (Jung-Beeman et al.) suggested that these findings were caused by the same underlying brain activation [1, 8]. The response of the right temporal brain was identified as the main neural correlate of the experience of insight, because (a) it occurred approximately at the moment when the participants realized the solution to each of these problems, (b) the same area is involved in other tasks requiring semantic analysis and integration; and (c) gamma-band activity has been proposed as a mechanism for binding conscious information.

This assumption is supported by other neurophysiological data [8]. Significantly more activity in the alpha range was found before analysis than before analytical report was obtained on the parietal electrodes on the right. The authors localize this effect of internal insight in the time interval from −1310 ms up to −560 ms relative to the solution. In both intrinsic and extrinsic insight effects, no indicators of some error on time were found due to different response times. Moreover, repeated measures ANOVA confirmed the hypothesis that internal and external insights have the opposite effect on alpha power, with significant cross-talk between problem-solving strategy, that is, insight or analysis, and range, that generating or recognizing a solution.

5 Conclusion

Thus, the main trends in the change in ERP depending on the variants of recognition of visual illusions and oddball images are as follows. Complete recognition of illusions, which corresponded to insight in the model of our experiment, was accompanied by an increase in the amplitude of the P300 wave in the temporal-parietal regions on the right. With correct identification of one of the dual images, the activation of the N450 component was recorded in the frontal regions on both sides. Negative recognition was characterized by generalized symmetric activation of all ERP components, more pronounced in the posterior half of the brain.

Discussion of our results allows us to talk about two possible options for actualizing the mechanisms of long-term memory that ensure the formation of insight – the simultaneous perception of images as part of an illusion. The first of them is associated with the inhibition of the frontal cortex at the stage of synthesis of information flows with the subsequent activation of the posterior parts of the brain and, most likely, is directly related to the mechanisms of "extra-logical" thinking. The second variant is traditional and manifests itself in the activation of the anterior sections of the neocortex with the subsequent excitation of all brain fields by the mechanisms of "exhaustive search".

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Self-regulation Approach for Setting Goals in Problem-Solving

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Abstract. In the self-regulation model of decision-making under uncertainty, the dynamic programming principle of optimality transforms into the principle of instrumental rationality, according to which the proximate goal should be reached from the perspective of attaining the distal goal. The solution of the problem is considered to be a result of multiple iterations in evaluating an alternative's pros and cons from the perspective of the distal (long-term) goal. This paper demonstrates how the self-regulation approach for setting and resetting goals when making difficult decisions helps differentiate the alternatives and find the most suitable course of action by recognizing cons in proximal positive outcomes and pros in proximal negative outcomes, or by changing the new distal goal, which should be more long-term than the previous one.

Keywords: Setting goals in problem-solving · Framing effect · Self-regulation model of decision-making · Rules of regulation · Feedback and feedforward controls · Energy-based factors of significance and difficulty · Dynamic programming of the level of motivation · Bounded rationality · Principle of instrumental rationality

1 Introduction

Problem solving includes the continuous reformulation of a problem and the development of its corresponding mental models. Heuristics help to disaggregate complex problems into simpler sub-problems with corresponding sub-goals. Very often, at the beginning of problem solving, the goal of the problem-solving task can be formulated in a very general manner, so that only later does the goal gradually become clearer and more specific. A goal can be revised at the later stages of the self-regulation process of problem solving in cases when it becomes evident that this process was incorrect or insufficient to differentiate the level of motivation for different alternatives. This allows the individual to make a decision concerning whether the alternative with the highest level of motivation will be executed, or if its level of motivation is not high enough, which would then require new alternatives to be added for consideration.

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When solving problems under uncertainty and making difficult decisions, it is necessary to consider their distal outcomes along with the proximal ones, in order to differentiate between different alternatives. The difference in evaluating alternatives typically comes from recognizing cons in proximal positive outcomes and pros in proximal negative outcomes of these alternatives. In the goal-setting process, it is important for the goal to be verbalized. This allows to implement the principle of instrumental (goal-processing) rationality when a complex problem is split into sub-problems. According to this principle, the goal of each sub-problem must be a sub-goal in order to rationally attain the long-term (distal) goal; in other words, the proximate goal should be reached from the perspective of attaining the distal goal. Here, the solution to the problem will be a result of multiple iterations in evaluating pros and cons of an alternative from the perspective of the distal goal. The goal splits outcomes into positive and negative categories. Therefore, applying the principle of instrumental rationality in setting proximate and distal goals provides more accuracy in splitting outcomes; this in turn helps identify the difference in evaluating alternatives based on their pros and cons, which makes the decision itself more accurate. Moreover, because the decision is made from the perspective of the distal goal, this classifies the decision as user-centered, as opposed to problem-centered decisions obtained from the perspective of the proximate goal when this principle is not applied.

In this paper we demonstrate how the self-regulation mechanism of setting and resetting goals contributes to overcoming difficulties in problem-solving.

2 Bounded Rationality of Decision-Making and Problem-Solving

In everyday life, people make decisions and solve problems. Most of the decisions that people make are done quickly, because this method does not create any problems for them. Problems come with difficult decisions, when the decision-maker cannot differentiate among available alternatives and/or the best alternative does not have a sufficient level of motivation for its execution.

According to Herbert Simon [1], *decision-making* is considered to be a process of evaluating and choosing among alternative actions, whereas *problem-solving* is considered to be a process of choosing issues that require attention, setting goals, and finding or designing suitable courses of action.

The theory of subjective expected utility (SEU) [2], a sophisticated mathematical model of choice that is the cornerstone of most contemporary economics, operations research and theoretical statistics, has been integral to the concept of prescriptive knowledge about decision-making. SEU theory outlines the conditions of an ideal *utility-maximizing rationality* in a world of *certainty* – in other words, a world in which decision-makers are able to provide the probability distributions of all relevant variables. SEU theory deals exclusively with decision-making; it does not in any way focus on *framing* problems, setting goals or developing new alternatives.

In light of this, D. Kahneman and A. Tversky [3] suggested prospect theory: a behavioral-economic theory that describes the way in which people choose between probabilistic alternatives involving risk. Instead of relying on goal-setting, prospect theory operates with the "*framing effect*," in which individuals who face a decision problem might have a different preference if considering a different framing of the same problem [4]. The framing effect functions as a cognitive bias in which people select alternatives that appear most appealing to them, based only on whether these alternatives are presented with positive or negative connotations – i.e. either as a loss or as a gain. People largely tend to avoid risk when an alternative is presented in a positive frame, and conversely, they tend to seek risk when an alternative is presented in a negative frame. In paper [5] we demonstrated how framing leads to a violation of the logical principle of extensionality in decision-making, which states that making a decision in a problem should not be influenced by how the problem is described. It should be noted that instrumental rationality of the prospect theory is based on linear optimization, which primarily deals with relatively well-structured decision problems.

Prescriptive theories of choice, such as SEU, are supplemented by empirical research demonstrating how people actually make decisions (purchasing insurance, investing in stocks, or voting for political candidates), as well as the processes people rely on to solve problems (reducing cholesterol levels or finding the best ways to pay off debt). This research has established that people *solve problems* by means of a selective *heuristic search* through large databases and problem spaces, implementing *means-ends analysis* as the key technique to help guide this search.

SEU theory and its subsequently established developments possess a key limitation: their relative neglect of the limits of human (and computer) problem-solving capabilities in the face of real-world complexity [1]. These limits are inadvertently imposed by the inherent complexity of the society in which humans live, which encompasses multiple restrictive factors, such as inconsistencies of individual beliefs and preferences, insufficiency of human knowledge, conflicts of value/interest among people, and inadequacy of the computations humans can carry out, even when relying on the most powerful computers.

H. Simon outlined the idea of the theory of bounded rationality [6]. This theory aims to describe how individuals actually make decisions in situations of uncertainty in which the conditions for rationality are not met: "decision makers can satisfice either by finding optimum solutions for a simplified world, or by finding satisfactory solutions for a more realistic world …" Bounded rationality is not a study of deviation from rationality, as it is believed to be by many psychologists [7]. In his essay in memory of Herbert Simon, Arrow insists that "boundedly rational procedures are in fact fully optimal procedures when one takes account of the cost of computation in addition to the benefits and costs inherent in the problem as originally posed" [8].

In [5] we demonstrated the role of *instrumental* and *value rationality* in decision-making under uncertainty. Instrumental rationality relates to achieving a goal, while value rationality is tied to the goal's particular value (epistemic, moral, ethical, etc.).

3 Self-regulation Model of Decision-Making

The self-regulation model (SRM) [9] is developed within the framework of the systemic-structural activity theory (SSAT) [10]. A distinctive feature of this model is the mandatory presence of the *goal* and an emphasis on its achievement, which is important for mental activity associated with decision-making and problem-solving. A goal performs integrative functions in the self-regulation process. It is important to emphasize here that not only does the goal divide the outcomes into positive and negative categories [11] and assign them a marker of subjective importance, but together with the conditions of the problem (problem = goal + conditions for its attainment), the goal also provides another marker for the outcomes: the difficulty of obtaining them (for positive outcomes) and the difficulty of avoiding them (for negative outcomes). Both of these markers form an integral marker for the results – the level of motivation. The goal and the motivation for its attainment create the *vector motive-goal*, which provides a goal-directed character to the self-regulation process [12]. As a result, setting goals in problem-solving scenarios helps make difficult decisions.

SRM includes two sub-models: *formation of the mental model* (FMM), which is executed by the divide-and-conquer (D&C) algorithm, and *formation of the level of motivation* (FLM), which is performed by the dynamic programming (DP) algorithm. Their interaction is regulated by feedback and feedforward controls.

Feedback control provides a connection between FMM and FLM models. It is regulated by the *factor of difficulty*, which determines the individual's self-efficacy in attaining the goal. Feedback control is corrective, connected to the individual's past experience, and provides robustness and error elimination in formation of the mental model and the level of motivation.

Feedforward control produces upgrades in FMM and FLM. It is regulated by the factor of significance, which determines the directness to the goal. Feedforward control is predictive and leads to an upgrade in the existing mental model or level of motivation in order to enhance its ability to solve a problem and obtain the desired outcomes.

In SRM, FMM and FLM are two concurrently running processes with two main regulators: the factor of significance and factor of difficulty that determine eight core *information-* and *energy-based* performance shaping factors, as well as four core criteria of success: positive and negative significance, and positive and negative components of difficulty [5].

There are four primary rules of self-regulation SR1 – SR4, in which the energy-based factors of significance and difficulty are assigned a key role [13]. In particular, rule SR4 regulates *setting and resetting goals.*

According to rule SR4, **–fb_FLM ⇒ ff_FMM**, negative feedback on formation of the level of motivation activates feedforward control of formation of the mental model (DP algorithm in FLM upgrades D&C algorithm in FMM). This means that if difficulty in evaluating the level of motivation (*energy-based component of difficulty*) is not adequate, then the *energy-based component of significance* determines whether the goals of the problem should be modified and the decision-making process repeated or completely terminated.

4 The Principle of Instrumental Rationality for Setting Goals in Problem-Solving

Setting and resetting goals as part of the formation of the mental model (FMM) is regulated by the dynamic programming (DP) algorithm to form the level of motivation (FLM) and apply rule SR4 of self-regulation.

DP with Richard Bellman's *principle of optimality* is an extremely powerful tool for solving a wide variety of sequential and well-defined (quantitative) decision-making problems under uncertainty. According to this principle, "An optimal policy has the property that, whatever the initial state and initial decision are, the remaining decisions must constitute an optimal policy with regard to the state resulting from the first decision" [14]. DP computes optimal decision rules that specify the best possible decision to take in any given situation. However, formal DP [15] and its extensions to multi-criteria optimization [16] have not been widely adopted thus far for the intention of improving individuals' decision-making. This is due to the fact that the DP model typically functions with a predetermined goal, is information-based, and performs consecutive processing of quantitative information, regulated by external feedback (such as dynamically changing budget constraints).

When applying the self-regulation approach, the individual's mental model becomes much more complex, since it is no longer simply *information-based*; it also becomes *energy-based*, with emotions playing a major role in its framework. It also includes *parallel processes* related to the simultaneous formation of both a mental model with goal-setting and the level of motivation for selecting the best alternative. This is why the decision alternative that might appear to be more risky and less worthwhile from an objective perspective may in fact turn out to be most preferable and appealing to the individual, since they already know how to overcome existing difficulties on the path to a goal by relying on their personal knowledge and experience. Here, decisions are not programmed by a previously constructed mathematical model (as is the case with DP), but rather by self-regulating processes that lead to the formation of the mental model of the thinking process. The obtained solution is not optimal, but rather rational (or *satisficing*), and its rationality is bounded due to humans' limited thinking capacity, available information, and time constraints [1].

In SRM, the principle of optimality transforms into the *principle of instrumental rationality* – i.e. the rationality that focuses on achieving a goal: "the goal of each sub-problem must be a sub-goal in order to rationally attain the long-term goal" [13]. In other words, achieving the proximate goal should be framed from the perspective of attaining the distal goal. Here, the solution to the problem would be a result of multiple iterations in evaluating an alternative's pros and cons from the perspective of the distal (long-term) goal.

In *decision-making,* a goal is typically a proximate (short-term) goal (something you might do right away) that cannot be clearly verbalized and exists as a purpose with a low level of conscience. Decision-making is a self-regulative thinking process in which the user splits a difficult-to-evaluate problem into sub-problems. This is done to form such a mental model that will allow the user to clarify an uncertain goal and form the level of motivation necessary for choosing the best alternative action. The final choice is a result of multiple iterations in evaluating an alternative's pros and cons from the perspective of the proximal goal.

Problem-solving includes setting distal and intermediate goals and finding a suitable course of action when the problem is uncertain. Because the problem is considered to be a goal in given conditions, goal setting changes the problem. A problem with a new goal is considered to be a new problem. When solving problems under uncertainty and making difficult decisions, the difference in evaluating alternatives typically comes from recognizing cons in proximal positive outcomes and pros in proximal negative outcomes of these alternatives. For goal setting, it is important for the goal of the problem to be verbalized**.** This allows to implement the principle of instrumental rationality in the first step of problem-solving when a difficult problem is split into sub-problems.

Therefore, problem-solving under uncertainty with a verbalized proximate goal demonstrates instrumental rationality in reaching the distal goal. In order for the problem to be solved in an instrumentally rational way, its goal (proximate goal) must be clarified in such a way that this goal becomes the *intermediate* or *sub-goal* in the rational solution from the perspective of the distal goal. The instrumentally rational solution will not be obtained for the initial problem, but rather for its modified version with a clarified goal. Because the goal splits outcomes into positive and negative categories [11], applying the principle of instrumental rationality allows to clarify the problem's goal and provides *more accuracy* in splitting outcomes; this, in turn, helps determine the difference in evaluating alternatives based on their pros and cons, which makes the decision itself more accurate. Figure 1 demonstrates how outcomes are divided into positive (+) (or pros) and negative (-) (or cons) categories in different ways, depending on whether they are viewed from the perspective of achieving the proximate (short-term) goal or distal (long-term) goal.

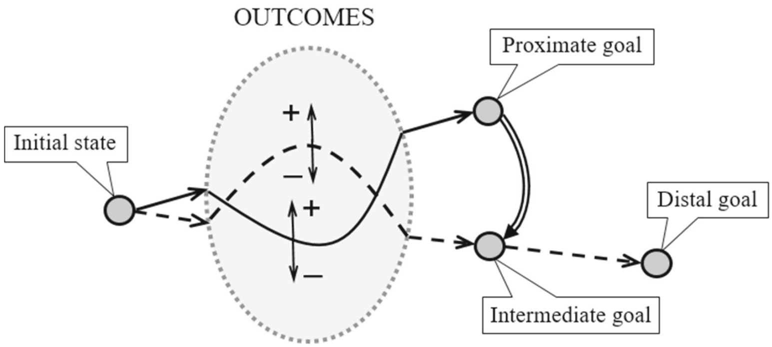

Fig. 1. Goal setting in problem-solving. Transforming the proximate goal for the purpose of attaining the distal goal.

Making the distal goal even more distal helps differentiate the alternatives by recognizing both the cons in proximal positive outcomes and the pros in proximal negative outcomes, and ultimately, this will allow to find the most suitable course of action.

5 Conclusion

Unlike subjective expected utility theory, the suggested self-regulation approach for setting goals reflects the decision-maker's thinking activity. This activity is bounded by human cognitive and other limitations, but nonetheless, it remains instrumentally (or processing) rational. This rationality is based on rules of self-regulation with core performance shaping factors and criteria of success, and it is driven by the principle of instrumental rationality. The role of setting and resetting goals is increased when solving difficult problems under uncertainty. The self-regulation approach for setting distal and proximate goals helps differentiate the alternatives and find the most suitable course of action by recognizing cons in proximal positive outcomes and pros in proximal negative outcomes. This approach also helps when a distal goal should be reset. This happens when the decision-maker is not motivated to choose any of the available alternatives. In this case, the most suitable course of action can be chosen by reevaluating each alternative from the perspective of a new distal goal, which should be more long-term than the previous one.

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Worker Engagement in Routinized Structured Activity Circumvention: Using SSAT to Understand the Significance of Involuntary Cognitive Intentionality

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Abstract. This study explored workers engagement in involuntary cognitive intentionality leading to their circumvention of structured and routinized activities at the workplace. Guided by Bedny and Karwowski's postulation that activities of individuals are realized by goal-directed actions, informed either by mental or motor conscious processes, as objects of the cognitive psychology of skills and performances, qualitative data was collected from documented interactions between graduate students engaged in research work and their supervisor, and analyzed morphologically to understand the significance of workers involuntary cognitive intentionality in different work setting. It was found that individuals assigned consciously designed and assigned structured activity in work-settings can think that they know how to do such activities better, and even understand everything about how to do the activity properly in their minds. It is concluded that workers involuntary cognitive intentionality makes them circumvent consciously designed and assigned routinized structured activity, yielding outcomes that deviate from expectations.

Keywords: Routinized activity · Structured activity · Activity circumvention · Involuntary cognitive intentionality · SSAT

1 Introduction

Workers' tendency to circumvent routinized structured activities is a phenomenon that occurs in several work setting, but which phenomenon remains unexplored. Understanding the role of involuntary cognitive intentionality in workers under- or over-performance is now a pre-requisite towards improving task design at the workplace. It has been argued by [1] from the perspectives of [2] that the number of activity task that a person has to learn must serve as the major criterion of determining the level of his/her cognitive and motivational-emotional aspects of the complexity entailed in his activity undertaking. As it was highlighted by [1], a person engaged in an activity is likely to use his/her generic skills to enhance the cognitive aspect of complexity associated with his/her

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object-oriented and subject-oriented activity [1]. Such generic skills, as outlined by [3], include the person's technical intelligence and sensibility, perceptive ability, sense of responsibility, flexibility independence, and trustworthiness.

During task performance, a goal can be formulated more specifically through a mechanism that is subjectively relevant to task condition, enabling a person to develop dynamic mental models of his/her assigned activity in both verbally logical and imaginative forms [4]. According to [4], the developed mental model of the task, which can vary even if an activity's instructions do not change, is the enabler for a person to create a subjective representation of his/her activity. In this stead, the person can re-orient an assigned activity to match his/her own subjective activity representation in an imaginative form [4]. According to [5], an increasing number of studies of involuntary conscious memory have shown that spontaneous recollections in self-reports occur in various contexts, including episodic memory tasks [6, 7]. According to [5], persons who are self-deceivers mostly make efforts to subjectively and voluntarily collect true information to convey to the deceived. This is because such persons are deemed to be honest not only to themselves, but also to the one being deceived [5]. However, in the process of conveying true information, self-deceivers unconsciously or involuntarily or unintentionally withhold such information [5].

According to [8], intentionality, as a psychological principle, is an invocation of ones understanding of self and others. In this regard, there is the tendency for one to use the implicit versions of intentionality and causality principles for one's integrated mental models of one's world, which models one can situate as the only one that matter [8]. According to [8], model-building is a powerful approach to theorizing about the dynamics of things. A model is visualized by [8] as a real representation of an entity which predicts aspects of the realistic occurrence and dynamics of things, providing one explanation of such entity in the process. Such entity could be a hypothetical representation of relations, constructs, and influences, which does not necessarily mirror real entities [8]. With such occurrence among workers in the world of work, it could be argued that an infected worker's unconscious mind is not going to be the one reaching conclusions regarding the consciously structured task that has been designed and assigned him/her. Though, it is a known fact that when a person thinks, such person is presumed to be aware of what he/she is thinking, it is also to know how much of the person's thought is unconscious, and how much of such thought occurs without the person's awareness. Thus, it is imperative to know how much of a person's thought help him/her make decisions and reach conclusions when assigned consciously designed work activity. Underline by the notion that a person might occasionally make a decision or reach a conclusion without his/her awareness, it is imperative to also delve into the dynamics of a worker's unconscious thought and exact its meaning relative to his/her task undertaking. Since such dynamics is becoming quite observable among university graduate students who at their educational levels, are expected to follow supervisory guide provided them by research supervisors in the course of their research work, this study explored students engagement in involuntary cognitive intentionality leading to their circumvention of structured and routinized research activities outlined by for them by supervisors.

2 Literature Review

Any scientific explanation of change, according to [8], is likely to invoke non-physical entities, such as forces and causal relations. Though such non-physical entities might seem manifest, they are in some sense inferred, and thus hypothetical [8]. In that sense, [8] argued that virtually all scientific explanation of change occurs in the form of models. According to [8], hypothetical entities, in some scientific explanations, are believed to mirror actual entities. Such scientific belief is based on the psychological notion that a conscious thought is something that is clear to a person, with unconscious thought being shrouded by events that simply mean anything that communicates information to a person's mind [8]. Using [9]'s arguments as psychological point of departure, it could be assumed that, such worker-oriented thought, when informed by the characteristics of the worker's consciously designed and structured job activity, can communicate to him/her everything there is in existence that his/her mind can understand. This postulation is rationalized by [10], argument that the involuntary entering of perceptions and urges into a person's consciousness is a fact of everyday experience. To such a person, as explained by [10], the content of such consciousness evolve involuntarily making it difficult to suppress.

It has been outlined by [11] that in the task interpretation process, the worker has to be able to involve his personal prerequisites such as experience, skills, and physical constitution, as well as his/her context as part of social systems inside and outside the organization [11]. Additionally, the worker has to solve all the problems that are not taken care of or misinterpreted when management design tasks, a situation that most often leads to employees' display of overt or passive–aggressive resistance to changes in work practices [12]. Such employee resistance could be remedied by developing technological process management, organizational design and learning that could be used to harmonize the functional relationship between the technical and the social components of the work system [11]. The significance of such harmony creation is defined by the realization that in order to design an efficient and effective activity, there is a need for the creation of knowledge on the harmonious integration of the activity's technological, organizational, and human systems [11]. This is because, a person's activity goal formation, as situated by [4], is a dynamic interaction between the person's assessment of the meaning of the activity's input information and its derivative sense, as well as the person's evolved motive and past experience(s). The meaningfulness of a person's interpretation of the activity's input information, according to [4], is an important element in the goal formation process. Such meaningfulness is extractable from both external data and a person's memory [4]. Thus, a person's strategies of gathering and interpreting information in an activity, as integral part of the his/her thinking processes, entail not only cognitive features, but also emotional evaluative and motivational features [11, 13, 14]. It is argued by [11, 13] and [14] that the strategies are controlled by the mechanism of self-regulation that characterize their dynamic nature to meaning and sense, both emotionally motivational and semantic, which causes a person to make a totally different sense of an activity within the same situation. Hence, a person's strategies of activity performance can be presumed to be influenced by factors associated with his/her background. Such factors included the person's professional and general knowledge, procedural knowledge acquired from experiences in past activity undertakings, and his/her knowledge of acceptable cultural behavioral norms that underline the functionalities of communities [13]. Depending on the specificity of a situation, and a person's pre-existing emotionally motivational state, he/she will develop a mindset imbibed with a tendency to come out with specific strategies for information gathering and interpretation [13, 14]. These strategies, as characterized by [13, 14], are dependent on the self-regulation mechanisms of activity, and could be conscious or unconscious. By implication, when the input information provided the person has optimal complexity and matches his/her past experience, there is a high likelihood that his/her interpretation of the input information will not vary from his/her subjective meaning informed by his/her procedural knowledge. On the contrary, when the person's past experience differs significantly from the input information, substantial interpretive variations of the same information can be observed between person and others [11, 13, 14]. Thus, the specificity of a person's goal formulation, his/her personal sense and interpretation of meaning, is significantly dependent on the degree to which the person allows his/her procedural knowledge from his/her past experience inform his present activity [11, 13, 14].

3 Methodology

Numerous efforts as exemplified by [15, 16], have been made to develop suitable methods for task complexity evaluation, including the use of various units of measure, such as the number of controls and indicators, or the number of actions. But there is the argument that task complexity cannot be successfully evaluated by such methods, principally because they employ incommensurable units of measure [13]. This therefore suggests that while task complexity can be evaluated both experimentally and theoretically [13], expert judgments, can also be used for the subjective evaluation of an activity's complexity [11], as well as the historicity, goal formation, strategy formulation and outcome decision-making associated with the activity [1, 11, 14]. In this study, the subjects' outcome-decision formulations in conformance to assigned structured routinized activity was analyzed using expert subjective interpretive judgements. Based on the well-established knowledge (e.g. [3, 11, 13, 14]) that activities of individuals are realized by goal-directed actions, informed either by mental or motor conscious processes [13, 14], as objects of the cognitive psychology of skills and performances [3, 11, 13], acts manifesting individual's involuntary cognitive intentionality was extracted from texts in email supervisory communications between students (subjects) as research undertakers and a supervisor. All the subjects studied involved are graduate students conducting research work under supervision at the University of Ghana Business School. Being graduate students, they all have first university degrees, and as such, were highly educated and expected to be diligent in following guide templates provided them in the assigned research tasks.

Using the systemic analytical approach [11, 13], functional analysis was conducted on the extracted text in email supervisory communications between task undertakers and supervisor to situate the character of the subject's goal formation, activity strategies and decision outcome relative to their assigned supervisory task. The sensemaking technique was then used to establish whether the subjects engaged in the circumvention of their routinized structured activity, and whether such circumvention was characterized by involuntary cognitive intentionality.

4 Results and Discussion

4.1 Outline of Supervisory Research Activity Guide

The following supervisory research activity guide was consciously designed and communicated to twenty (20) graduate students (subjects) who are undertaking master research work activity by the supervisor.

I am providing you, in advance, a template to guide you on how to go about the analysis, as you round up your data collection. The analysis requires patience and diligence, and you will be expected to go strictly by what you see in the template without adding anything that is not part of it. Study the template carefully and then compare it with elements in your questionnaire. You can see that each section in the template matches with each number under the different sections in your questionnaire. When you are done with the data collection, you can proceed by doing the following.

- Replace all the parts in the template marked in red, where you can.
- Fill in the various tables by putting in the appropriate figures. Each table represents each number in the questionnaire from 1 to the last number.
- After completing the table, use Microsoft Excel to plot the figures exactly as you see them below each table using the portions marked in blue colour for the plots. Replace the figures you see with your new plotted ones.
- Continue and do the write-ups after the figures, as shown in the attached template.
- The write-up marked in green is to draw your attention to pick the right values from your tables.
- The write-up marked in blue is to draw your attention to replace the sentences with the appropriate ones as inferred from your sections.

Before the students proceeded with the assigned activity, the supervisor provided the students opportunity to seek clarification in the event of non-clarity, which was not utilized by all students.

4.2 Supervisor-Students Exchanges on Students' Output Conformity

Assessment of the output report received from the twenty students after completing the assigned guided activity, showed that six (6) students deviated from the guide provided. The exchanges below ensued in the correspondences between the supervisor and the 6 students deemed to have deviated from the provided guide. The students are labelled with symbols SA, SB, SC, SD, SE, and SF.

i). *Supervisor to SA*: I am wondering your seriousness. Did you check before sending it over? You did not follow the guide provided.

Response by SA: Please pardon my omission. Thank you

ii). Supervisor to SB: It looks like you are not serious. You did not follow the guide. Do as instructed in the mail!

Response by SB: Mail well noted. Thank you

iii). *Supervisor to SC*: I am quite disappointed. You did not do what I asked you to do.

Response by SC: Sorry Sir. My I used my own understanding to do the work.

iv). *Supervisor to SD*: What you sent does not make sense. Do the right thing !!!

Response by SD: Thank you for the feedback.

v). *Supervisor to SE*: Hello, you chose not to follow the directions I provided you. I wonder if you read the work before dispatching it to me. Kindly follow the guide I sent you.

Response by SE: Thank you Sir, I appreciate the outline you gave, it made the work much easier.

Supervisor to SE: Please, be cautioned once again. You still did not use the guide. I am going to give you another opportunity to do the right. I hope you will do the right thing!

vi). *Supervisor to SF*: Hello, be reminded that the supervision process is not a joke. I sent you a guide on what to do. Instead of doing what is expected of you, you destroyed the sense of what I sent you. Kindly do what you were guided to do.

Response by SF: Good evening. I render my sincere apology. I will work on it and revert please. Thank you for your time and patience.

Analyzing the exchanges between the supervisor and the various subjects outlined above, it could be inferred that the subjects are fully conscious of the significance of the guide provided them by the supervisor. The fact that they sounded apologetic after the supervisor had drawn their attention to their non-usage of the guide is indicative of their circumvention of the consciously designed routinized structured activity assigned them by the supervisor. Analysis of the communications indicate that the actions of the subjects are reflective of involuntary cognitive internationalities. Aside subject C who chose to use self-understanding contrary to the guide provided, the remaining subjects (i.e., SA, SB, SD, SE, and SF) appeared to have held the notion that they did what was expected of them, as manifested in their being apologetic in their responses to the supervisor. This observation shows that aside subject SC whose non-usage of the guide provided could be classified as influenced by a conscious activity strategy, the actions of the remaining subjects (i.e., SA, SB, SD, SE and SF) could be have been informed by their unconscious activity strategies that resulted in the functioning of their flexible mental systems towards the unconscious operations [13] they undertook that resulted in the output they sent to their supervisor. For subject SC, there is the probability that the use of self-understanding in diagnosing and performing the assigned activity, in contradiction to the guide provided, resulted in the application of conscious strategies to carry out the assigned task by the supervisor, but which information and interpretation, though meaningfully to the subject, deviated from the expected meaning by the supervisor. Thus, the strategies used by all the subjects that resulted in the voluntary deviation (subject SC) and voluntary deviation (subjects SA, SB, SD, SE, and SF) shows the dynamism of the algorithmic and stochastic characteristics of their sensemaking in their activity performances [11, 13, 14]. It could therefore, be inferred that in the subjects assessment of the consciously designed structured activity assigned them by the supervisor, they consciously (subject SC) and unconsciously (subjects SA, SB, SD, SE and SF) exacted meaning of the immediate input information provided in the guide by the supervisor, which interacted with their respective past experiences [11, 13, 14], probably as first degree holders who might have been introduced to first degree-level research apriory. Such cognitive understanding of how persons make personal sense of objective input information is of relative significance towards understanding the dynamics of involuntary deviations from assigned structured activities. Therefore, arguing from the perspectives of [11, 13] and [14], the prior observation implies that a person's interpretation of input information in an assigned structured activity will not vary from the person's personal sensemaking that emanates from the person's procedural knowledge, if such information entails optimal complexity that associate with the person's past experience. But, when the input information in the assigned structured activity differs from the person's past experience, it results in interpretive variations ([11, 13, 14]) that could lead to involuntary cognitive intentionality, that could result in routinized structured activity circumvention.

5 Conclusion

The results showed that individuals assigned consciously designed and assigned structured routinized activity in work-settings can think that they know how to do such activities better, and even understand everything about how to do the activity properly in their minds. This was found to lead to the situation of involuntary cognitive intentionality whereby they circumvent consciously designed and assigned routinized structured activity, yielding outcomes which mostly deviate from that expected from their actual activity performances. It is also found that workers engagement in such involuntary cognitive intentionality is informed by the psychological notion that when a person is doing something, such as a routinized activity that he/she knows how to do, there is the possibility that he/she might automatically engage in involuntary cognitive intentionality without thinking. It is concluded that the tendency for a person to deviate from assigned routinized structured activity is informed by the realization that such person has the ability to strategize his/her creative problem-solving and skill development capabilities towards attaining the set-goals of the assigned structured routinized activity. It is also concluded that the emergence of a person's involuntary cognitive intentionality in the conduct of designed and assigned routinized structured activity that results in activity circumvention is influenced by the effect of the person's procedural knowledge from past experience on the specificity of his/her interpretation and sensemaking of input information in the assigned structured routinized.

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Brain-Machine Interface (BMI) and Neuroinformatics

Design for AI-Enhanced Operator Information Ergonomics in a Time-Critical Environment

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Abstract. Maintaining situational awareness in time-critical operation control is an omni-dimensional optimisation problem. For excellent situational awareness, complete information with sufficient time to process it is prerequisite. Making sound judgement with limited time the flight controllers suffer poor information ergonomics as demanding situations cause cognitive load as well as incoming information is constipated. In this normative paper, design principles and main functionalities are presented for an artificial intelligence powered and extended reality decision support information system.

Keywords: Information ergonomics · Situational awareness · 3D presentation · Artificial intelligence

1 Introduction

Decision-making depends on accurate information to enable good situational awareness (SA). Good SA is a state when an individual has all relevant information about what is going on when the full scope of the task is considered. It is about what is happening as well as what is, and is about to be, the status of factors considered, i.e., a perception of the factors within the environment and a comprehension of their meaning and a perception of their status in a near future. Taking the perspective of information ergonomics, the quality of information is more important than the quantity, i.e., only critical information ~~is~~ should be presented as ~~more~~ excess information causes unwanted load to information processing [1]. Information related to decision making should be presented in the form of easily consumable information products in order to avoid distraction. The information-processing lag or additional processing cycles easily cause distraction. In an information driven operation management setting, the key issue is to concentrate on the most relevant information and to gain and maintain good SA. Adding time pressure as a factor presents

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an omnidimensional information processing optimisation problem. Optimisation is done according to the completeness of the information, the amount of the information and completeness of processing of the information. In traditional information management process models, such as those reported by Choo [2] or Savolainen [3], the mentioned factors are not discussed per se, but optimisation is seen as solved implicitly. However, literature on SA brings about the requirements for information, completeness of the information and processing of the information as discussed in Chen et al. [4]. According to Franssila et al. [1], such conditions are a significant ergonomic issue. Enhancing information ergonomics promotes performance and lowers ~~stress~~ cognitive load in work settings [5].

Methodologically, this paper follows the principles of decision-orientated research as positioned in Kasanen et al. [6]. Striving to be both normative and theoretical, this paper aims to provide new information which is applicable in practice and sketch a test procedure to validate the construct. The context of this paper is SA where an operator's task is to monitor multiple aircraft engaged in air combat. The known information about the aircraft's location, altitude, heading and speed. Traditionally this information is presented as a 2-dimensional (2D) visualisation with symbols and rich information to provide all necessary information. In order to enhance the information ergonomics, a 3-dimensional (3D) visualisation is proposed for the monitoring task. In the 3D presentation, some'information could be reduced as the three dimensions enable presenting relative position as well as location without numerical augmentation, thereby allowing a simpler visualisation. Clustering adds value to 3D presentation as the algorithm moderates how objects are presented, e.g., highlighted by certain criteria. In order to enhance the information ergonomics, the 3D presentation has less symbology than the 2D presentation and, in general, the notation is expected to be simpler and easier to comprehend with 3D. This means less objects to follow, less information to process, and more time to concentrate on relevant factors. Especially in time-critical decision making and operation management situations, artificial intelligence (AI) driven presentation of information could draw attention to noteworthy factors and reduce cognitive load. With lower cognitive load and less factors to pay attention to, the operator is likely to achieve a state of better information ergonomic state. The conclusions of this paper are the design principles for shifting from 2D presentation to 3D presentation as well as how to build the setting to operationalise it.

1.1 Measures of Information Ergonomics

Of all the possible measures of information ergonomics, this paper concentrates on those of SA and cognitive load. A variety of techniques are available to measure SA. These techniques can be broadly categorized as performance techniques [7], real-time probe techniques [8, 9], freeze-probe recall techniques [10, 11, 12, 13] post-trial self-rating techniques [14–16] and observer rating techniques [17–19]. Situation awareness global assessment technique (SAGAT) [20] is probably the most widely used freeze-probe recall technique. Before SAGAT can be used, a task of interest must be analysed to identify factors relevant to SA in that task. Then, probes about these factors are prepared. For example, in a piloting task an aircraft's altitude can be identified as a factor. A question: "What is the aircraft's altitude?" is a probe tapping the pilot's perception about that factor. When SAGAT is used, a participant engages in a simulated task. Then, at random intervals the simulation is paused, the visual of the simulation is blanked and the audio is faded away. While the simulation is frozen, probes relevant to that phase of the simulation are introduced. The probes are selected such that they tap the participant's perception (SA level 1), comprehension (SA level 2) and projection (SA level 3) in the task. Once the participant has answered the probes, the simulation is continued until the next freeze-point is reached. The procedure is repeated until simulation is completed and participants' responses to all probes have been obtained. The participants' responses to probes are compared to correct answers to those probes and used as an index of overall SA and SA levels 1–3.

Cognitive load can be assessed using physiological, behavioral, and/or subjective measures – each with their own strengths and weaknesses [21]. Subjective measures, such as the NASA Task Load Index (NASA-TLX) [22] have been widely used – mainly as they are non-intrusive and easy to implement (Mansikka, Harris & Virtanen, 2019). The NASA-TLX assesses cognitive load across six dimensions: mental demand (MD), physical demand (PD), temporal demand (TD), performance (OP), effort (EF) and frustration level (FR). When NASA-TLX is administered, two types of information about each dimension are obtained from the participants: weights and scores. The weights represent the subjective importance of each dimension as the source of cognitive load in the task of interest, whereas the scores express the subjectively sensed magnitude of cognitive load with respect to each dimension. According to Hart & Staveland [22], the weights are obtained by conducting pairwise comparison for every dimension pair. This procedure, however, is highly problematic and Mansikka et al. [24] provide several alternative, and more appropriate, methods for setting the weights. Once the weights have been set, the subjects engage in a task of interest and rate each load dimension based on their subjectively sensed cognitive load. A weighted cognitive load index for each dimension is calculated by multiplying each dimension's score by its weight. An overall load index is a weighted sum of the dimension scores, where weights have been normalized to the sum of one.

2 Information Ergonomics in the Context of Situational Awareness

Taking the definition of information ergonomics discussed in Franssila et al. [1] and Okkonen et al. [5], the load of information processing, the amount of information, and time pressure affect the ergonomic state of an operator. The foundation of sound judgement and decision-making is accurate, sufficient and targeted information about the key factors. SA is highly dependent on available time. Decision making under time pressure requires naturalistic decision making [24]. The SA model presented by Endsley [25, 26] identifies three hierarchical levels of SA: perception (level 1), comprehension (level 2), and projection (level 3). Perception is about recognising statuses, attributes and dynamics of the relevant factors within the environment. Comprehension is about combining information and building interpretation of the situation. Projection is about foreseeing the near-future states of the factors in the operating environment.

The role of AI in supporting SA links the OODA-loop (Observe, Orient, Decide, Act) and Endsley's SA levels AI supports the Observation and Orientation stages by improving perception and comprehension, i.e., SA levels 1 and 2. The quicker and less cognitively demanding it is to reach the Observe and Orient stages, the more time and cognitive resources are available for projection, i.e., Decide and Act stages. As stated by Endsley [8], for naturalistic decision-making, it is most relevant to extract relevant information fast and to make quick yet well-justified decisions.

A human-technology interaction perspective views AI as an activity, which assists humans to filter, manage, analyse and refine information in order to gain and maintain SA. Crowder, Friess and Carbone underline the independent role of technology in assisting the operators [24]. In order to better utilise the human information processing capacity, the AI refined information should be presented in a form which minimises the cognitive load cf. [25]. This can be achieved as AI excels with speed and ability to process a large amount of information [26]. AI can support gaining and maintaining all three levels of SA and decision-making. However, these support functions require that characteristics, rules and dependencies of the system elements have been identified and the AI has been taught and/or programmed accordingly.

For information ergonomics, the impact is still evident as AI curates the content, i.e. by the predesignated rules it, for example highlights the most noteworthy objects and keeps the attention on the relevant factors as discussed e.g. in.Crowder, Scally & Bonato [27]. On the other hand, the mode of the presentation has also an effect as some information is presented differently and no longer requires operator processing. Enhanced information ergonomics in the context of this paper is the product, not sum, of automated information processing combined with a more illustrative and natural presentation. Relateing to the organisational intelligence cycle, the augmenting role of artificial intelligence are sensing, perception, interpretation, and memory cf. [2, 28]. Adaptive behaviour is dependent on human attributes such as creativity and trust in on the sound judgement of the operators, not the algorithm.

3 Using 3D Modelling and AI Driven Clustering to Enhance Information Ergonomics in Time-Critical Activity

Enhancing information ergonomics is about a more balanced cognitive load and better SA. As discussed above, this could be achieved by shifting from 2D presentation to 3D presentation and/or representing AI driven information to the operator. A fighter controller (FC) is a military qualification given to a person trained to provide early warning (EW) and command and control (C2) services to military aircraft. As such, the FC is engaged in an operation control task. FC bases his/her control decisions mainly on aircraft position and speed. These are traditionally presented in2-dimensional visuals.

ls. The user interface of the operation control software has been developed such that it supports the FC's SA and decision-making. However, when the complexity of the displayed air combat situation increases, the 2D visual can become cluttered, causing unbalanced cognitive load and reduced SA – and eventually degraded task performance (cf. e.g. [5, 23]).

This paper demonstrates an AI driven 3D presentation for the FC's simulated operation control task. Utilising the simulation environment features, most functionalities are developed by using open interfaces. The algorithm for clustering the objects follows certain standard operation procedure rules derived from the context.

The role of AI in the demonstration is twofold. Firstly, it is utilised to rank simulation entities and their relations. Ranking is done according to the entities' position, heading and altitude. Based on a certain set of rules, all objects are visible, yet only the high-ranking ones are highlighted. Moreover, different modalities for feeding alarm, e.g., sound or haptics, could be added if certain criticality criteria are met. Secondly, AI is utilized to calculate and display relative qualities of the entities. For example, the time it takes for one entity to reach another entity can be calculated and displayed when appropriate. Thirdly, AI enables automated switching of viewpoint, i.e., scenarios could be presented from alternative viewpoints based on AI rules. Table 1 summarises the key features.

Table 1. Expected outcomes of certain features

Feature	Function	Outcome
3D	Easier perception	Less cognitive load and better SA
Clustering	Automated analysis	Less cognitive load and better SA
Relation information	Automated analysis	Less cognitive load and better SA
Different modalities	Attention	Attention at critical moments
Automatically highlighted objects	Easier perception	Attention to relevant items
Automated rendering	Several viewpoints	Better understanding on relative positions

3.1 Use Scenario

In real life, the FC relies on a recognized radar picture (RAP) to support the friendly, i.e., blue, aircraft. In this study, a RAP was generated using a Modern Air Combat Environment (MACE) simulation and threat environment (see, https://www.bssim.us/mace/). Two alternative apparatus were used to represent RAP to the FC. One apparatus was a 2D visual and the other one was a virtual reality (VR) goggles, which provided the FC with a 3D view of the RAP. When the 2D visual is used, FC is limited to a viewpoint directly above the blue and red. However, the FC was able to zoom his viewpoint in and out and to move it to any compass point. The VR goggles were connected to a hand controller, which the FC could use to change his viewpoint freely and to 'move' around the simulated environment. The simulation did not include audio.

Two air combat test scenarios, both with eight blue and eight enemy, i.e., red, aircraft are programmed into the Modern Air Combat Environment (MACE) -simulation environment. All aircraft are constructive simulation entities and scripted to follow predetermined behaviours. As a result, there is no differences in the scenarios between the different simulation runs. The blue aircraft are programmed to intercept the red aircraft and vice versa. Both scenarios are designed similarly in terms of SA demands and mission complexity. In both scenarios, the blue and red aircraft were initialized 100 nautical miles apart.

Before the trials, the FCs are allowed to train with both the 2D and 3D displays and controls until they feel comfortable using them. In the air combat scenarios, FC's task is to observe the scenarios and to build and maintain SA such that he could provide EW and C2 services to the blue aircraft if needed. The scenarios are randomized between the types of apparatus used by the FCs. For each FC, one scenario was observed with 2D visuals and the other was observed with VR goggles. Based on the training session, FCs provide weights for the NASA-TLX dimensions.

As the FC observes the scenario, the simulation is paused, and the displays are blanked at predetermined intervals. While the simulation is paused, the FC's SA levels 1–3 about the scenario are probed using SAGAT. Each simulation run will be paused several times and a sufficient number of probes for each SA level are used to tap the FC's SA. Table 2 summarizes the SAGAT probes planned for tapping the FC's SA at each simulation pause. Once the scenario is completed, the FC evaluates the subjectively sensed cognitive load experienced during the scenario and scored the NASA-TLX dimensions accordingly.

Table 2. SAGAT probes used to probe FCs' SA levels 1–3

SA level 1	SA level 2	SA level 3
What is the formation of the blue aircraft?	What is the tactical status, i.e., winning/losing/tying of the blue aircraft?	How long will it take until the blue aircraft must defend against the red aircraft?
What is the formation of the red aircraft?	Is the blue aircraft still able to adhere to the directed tactics?	How long will it take until the blue can launch missiles against the red aircraft?
What is the altitude of the red aircraft?	Which red aircraft are being engaged?	If the red aircraft continues with this geometry, will the blue missiles hit them?
What is the altitude of the blue aircraft?	Which blue aircraft are being engaged?	
What is the speed of the red aircraft?	Which blue aircraft have engaged which red aircraft?	
What is the speed of the blue aircraft?	Which red aircraft have engaged which blue aircraft?	

4 Concluding Remarks

This paper further developed the way to augment humans for better SA. Future tests will provide a better understanding of acceptance of AI and trust in technology pertaining to its designated'effect on SA. The acceptance is especially critical when considering the role of AI. Above, the role of AI was set as an assistant enhances human information processing capability and augments knowledge related processes. Despite the augmenting role of the AI, human technology interaction perspective should be taken into account when implementing it [29]. Acceptance and trust are related to several factors such as motivation, user perception of the presence, and expectations on performance and utility [30]. Expectations of human-like behaviour and delivery of process virtues as well as the securing of operations also relate to acceptance [31]. This is also an important factor when assessing the performance effect as productive utilisation requires acceptance. If there is a lack of trust, there will be a high risk of cognitive dissonance and double checking, which leads to vicious cycle of increased cognitive load and poor information ergonomics. In future experiments, the issues of trust and acceptance should also be taken on the agenda. The first order condition for utilisation is delivering utility with key features or functionalities. The intention of this technology itself' is not solely sufficient as user's role in operating environment also has great significance.

The forthcoming user study will also provide important data on several knowledge-processing related issues. The increased accuracy of SA along better information ergonomics is the proposition for the test phase. Also, the subjective sense of work-load while operating in different visual modalities is significant Cognitive dissonance, i.e. possible conflict between detected experienced and projected is an interesting issue to investigate as source for cognitive dissonance, i.e. is it caused by technology or mental factors.

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Feature Comparison of Emotion Estimation by EEG and Heart Rate Variability Indices and Accuracy Evaluation by Machine Learning

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Abstract. There has been a lot of attempts on estimating human emotions using physio-logical data, and it is expected to be applied to medical diagnosis. Recently, there is emotion estimation model using EEG and heart rate variability index-es as feature values, and applying deep learning to classify emotions with an accuracy of 61%. However, the accuracy may not be sufficient for applications such as medical diagnosis. In this study, we extracted and selected features of EEG and heart rate variability indexes in order to improve the accuracy. As a result, by using our proposed method to extract and select features, the accuracy of the model was increased to almost 100%.

Keywords: Emotion recognition · Feature selection · Feature extraction · Machine learning

1 Introduction

In recent years, there has been a lot of attempts on estimating human emotions in the engineering field [1], and it is expected to be applied to various scenarios such as human-robot interaction [2, 3] as well as healthcare and medical diagnosis [4, 5].

Ikeda et al. proposed an emotion estimation method using a combination of EEG and heart rate variability indices [2]. They used the Russell's circumplex model [6, 7], which classifies human emotions by two-dimensional space, Arousal and Valence, as shown in Fig. 1, and assigned EEG indexes to Arousal and heart rate variability (HRV) indexes to Valence to classify emotions into those dimensions.

There is a HRV index called pNN50, which has average value of 0.3 according to Francesco et al. [8]. Using this as a reference, Ikeda et al. assigned the pNN50 to Valence, and set 0.3 as the criterion to classify emotions: pNN50 $\geq$ 0.3 indicates pleasantness, and pNN50 $<$ 0.3 indicates unpleasantness. However, since there are individual differences in biological information such as EEG and HRV, the criterion of 0.3 may be inappropriate to apply in general.

To address this problem, Urabe et al. constructed an emotion estimation model for each individual using machine learning, particularly, deep learning [9]. As a result, the model achieved classification accuracy of 80% on average, and 100% at maximum for

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the four quadrants of HAHV, HALV, LALV, and LAHV in Fig. 1. However, the average accuracy of 80% may be insufficient considering the applications in healthcare and medical diagnosis.

In general, before constructing model by machine learning, feature extraction and selection are performed to obtain effective features as model input. By removing unnecessary features, the prediction accuracy can be improved. However, in the study by Urabe et al., the accuracy did not reach its full potential possibly because the feature extraction and selection were not sufficiently done.

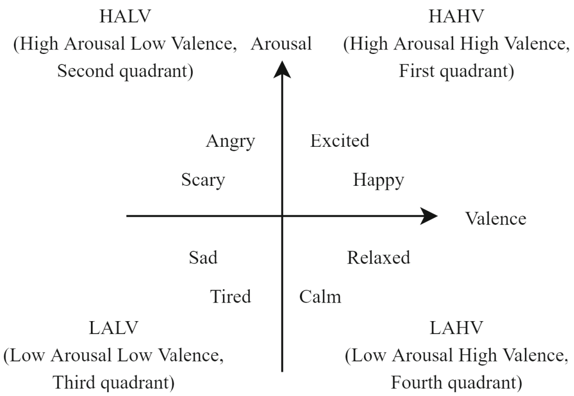

Fig. 1. Arousal-valence space model

Therefore, the purpose of this study are (1) to examine the EEG and HRV indexes used as features and (2) to compare the accuracies of emotion estimation when the indexes used for model construction are changed. We performed feature extraction and selection of the EEG and HRV indexes in order to increase the accuracy to estimate emotions using our model constructed by machine learning. An experiment was conducted to confirm the data collection method used for machine learning. In this experiment, we collected data from only one participant and only three emotional groups (HAHV, HALV, and LALV). Using this data, we evaluated the accuracies of the models constructed by four machine learning algorithms: deep learning (DL) using the same structure as Urabe et al. [9], Support Vector Machine (SVM), Random Forest, and Logistic Regression. The accuracy of the DL using the features in the previous study [9] was 61%. On the other hand, the accuracy of DL using the features proposed in this study was almost 100%, indicating that the accuracy has been improved.

This paper is organized as follows: Sect. 2 describes the feature extraction from EEG and heart rate variability data. Section 3 describes the feature selection method. Section 4 describes our experiment to collect data for model construction. Section 5 describes model construction and comparative results of machine learning accuracies. Section 6 discusses our results and future work. Finally, the last section concludes our study.

2 Feature Extraction from EEG and Heart Rate Variability

2.1 EEG Indexes

Electroencephalogram (EEG) is the recording of electrical signals in the brain using electrodes. EEG can be classified into different types according to frequency bands, each of which can represent different psychological states [10, 11]. In previous study [9], Urabe et al. divided the frequency bands and used them as EEG indexes as follows: θ: 1–3 Hz, δ: 4–7 Hz, α: 8–12 Hz, β: 13–30 Hz, γ: 31–50 Hz.

In this study, we employed the EEG indexes previously used by Ikeda et al. [2], Stamos et al. [6], and Urabe et al. [9], to classify the emotions into four groups on the Valence-Arousal space model. For the measurement of EEG indexes, we used Mindwave Mobile2 manufactured by NeuroSky Inc., which is a non-invasive EEG sensor with a single electrode placing in the vicinity of the left frontal lobe labelled as AF3 in the international 10–20 system. There were three types of new EEG indexes to be examined in this study as follows:

The first one is the subdivided frequency bands of EEG. They can be used to describe human states in detail. Specifically, we used EEG indexes in the following frequency bands: Low α: 8–9 Hz, High α: 10–12 Hz, Low β: 31–40 Hz, High β: 18–30 Hz, Low γ: 31–40 Hz, Mid γ: 41–50 Hz.

The second one is a moving average of EEG indexes with 15 intervals. EEG indexes are typically subject to severe fluctuations. Based on the idea that these fluctuations interfere with the minimization of the objective function and the calculation of the threshold in the machine learning algorithm using the EEG indexes, we employed moving averages expecting to reduce these inhibitions and estimate emotions more accurately. Since there are studies that use this method [12, 13], we believe that it has a certain validity.

The third is Attention and Meditation, which are indexes calculated by NeuroSky's original algorithm [14]. Since these indexes have been previously used to classify degrees of Arousal [2], we considered that they could contribute to the accuracy of machine learning in this study.

2.2 Heart Rate Variability (HRV) Indexes

The standard deviation, coefficient of variation, and frequency analysis of the Interbeat Interval (IBI), which represents the heartbeat interval, can be used as indexes of pleasantness, displeasure, sympathetic and parasympathetic nerves [15–18]. However, in the previous study by Urabe et al., they used only the pNN50 as HRV index.

The HRV indexes, LF and HF, were calculated by frequency analysis. Frequency analysis by Fast Fourier Transform (FFT) decomposed them into high frequency region HF and low frequency region LF. LF is said to reflect the sympathetic nervous system, while HF reflects the parasympathetic and sympathetic nervous systems. By calculating the ratio of these two (LF/HF), we can evaluate the state of a person [11].

In summary the following are the HRV indexes we employed in this study: heart rate (HR) representing the tense and calm, pNNx (where x = 10, 20, 30, 40, 50): the percentage of adjacent IBIs whose absolute value exceeds x milliseconds, SDNN: standard deviation of IBIs, RMSSD: root mean square of IBI differences, SDNN/RMSSD: SDNN divided by RMSSD, CVNN: coefficient of variation of IBI, LF: power value of IBI at 0.04–0.15 Hz analyzed by frequency, HF: power value of IBI at 0.15–0.40 Hz analyzed by frequency, and LF/HF: LF divided by HF.

The HRV was measured using an optical heart rate sensor that works with Arduino board from Switch Science.

3 Feature Selection

Two methods were used to select the EEG and HRV indexes as features for machine learning. The first method is to use the number of pairs of emotion groups (i.e., HAHV, HALV, LALV, LAHV) with significant differences calculated by one-way ANOVA as a reference, which has been used in other studies [19] as well. The second method is to use the importance of the indexes obtained from machine learning algorithm, Random Forest, as a reference, which has been used in other studies [20].

One-way ANOVA shows significant differences in physiological data between emotion groups, indicating that there are differences in physiological data on each emotion group. In this study, we used the number of pairs of significant differences as a reference to select the indexes as features.

The importance of the indexes, which is obtained from Random Forest algorithm, is a quantitative measure of how much each index contributes to data classification and estimation. We used this method based on the assumption that the indexes with a high importance can also contribute to classification and estimation by machine learning algorithms other than Random Forest.

4 Data Collection

In order to construct models by various machine learning algorithms and compare their accuracies, we first need to collect data of the EEG and HRV indexes under the emotion groups. Therefore, we conducted an experiment to collect these data. Our experiment employed music from a music database created by researchers at the University of Jyväskylä [21] as emotional stimulus. From this database, we arbitrarily selected music to elicit emotions corresponding to each of the four emotional groups.

In this study, subjective evaluation was used as a method to estimate emotion that was arisen by each music. The subjective evaluation was the Self-Assessment Manikin (SAM) scale, which is an evaluation method to select the manikin that is closest to one's own feelings. In this way, we can determine which quadrant of the Arousal-Valence Space Model the emotion belongs to, in other words the four emotional groups. Using the above emotional stimulus and subjective evaluation, we conducted an experiment with a male participant who is in his twenties. EEG and HRV data were acquired while the participant was listening to the music.

The experimental procedure is as follows:

(1) Participant sits on a chair and wears EEG sensor, heart rate sensor, and earphones,

(2) As a practice, participant performs a simplified version of step (3). Then, he waits quietly for 5 min,
(3) Participant is asked to perform 8 trials, each of which consists of 3-min rest, 1-min music listening, and a subjective evaluation of the emotions elicited by the music.

The numbers of data obtained in the first (HAHV), second (HALV), third (LALV) and fourth (LAHV) quadrants were 122, 60, 0 and 303, respectively. We intended to collect the data of the emotions belonging to all quadrants. However, according to the results of subjective evaluation, the emotions in LALV were not elicited. Therefore, we only examined the features for the estimation of the three emotions, HAHV, HALV, and LAHV, in the first, second, and fourth quadrants.

The significant differences between three emotion groups from the one-way ANOVA results for some of the features are shown in Fig. 2.

θ

\	1	2	4
1	\	○	○
2		\	×
4			\

δ

\	1	2	4
1	\	○	◎
2		\	×
4			\

α

\	1	2	4
1	\	×	×
2		\	×
4			\

β

\	1	2	4
1	\	×	×
2		\	×
4			\

γ

\	1	2	4
4	\	×	○
2		\	×
1			\

MA15 θ

\	1	2	4
1	\	◎	◎
2		\	◎
4			\

MA15 δ

\	1	2	4
1	\	◎	◎
2		\	◎
4			\

MA15 α

\	1	2	4
1	\	◎	◎
2		\	◎
4			\

MA15 β

\	1	2	4
1	\	◎	◎
2		\	◎
4			\

MA15 γ

\	1	2	4
1	\	◎	◎
2		\	◎
4			\

LF

\	1	2	4
1	\	◎	◎
2		\	◎
4			\

HF

\	1	2	4
1	\	◎	◎
2		\	◎
4			\

LF/HF

\	1	2	3
1	\	◎	◎
2		\	◎
4			\

Fig. 2. This figure shows some of the results of the one-way ANOVA. The numbers 1, 2, and 4 represent the first (HAHV), second (HALV), and fourth (LAHV) quadrants of the Valence-Arousal Space model, respectively. Only a few characteristic results will be described. × indicates no significant difference, ○indicates a significant difference at $0.001 < p < 0.05$, and ◎indicates a strongly significant difference at $p < 0.01$. The bottom left corner of the table is symmetrical with the top right corner, so it is omitted.

As shown in Fig. 2, there were significant differences for all three cases in all indexes calculated by frequency analysis (i.e. LF, HF, and LF/HF) as well as all indexes with moving averages (i.e. MA15 θ, MA15 δ, MA15 α, MA15 β, and MA15 γ). Therefore, we expect to improve the accuracy of emotion estimation by using these indexes as features, as there might be certain relationship between these differences and emotions.

Furthermore, we obtained the importance of indexes calculated by Random Forest as shown in Fig. 3. The importance levels were calculated by averaging the five importance levels calculated in the stratified five-fold cross-validation.

The result shows that LF, HF, and LF/HF, which have the highest number of significant differences, also have the highest importance. On the other hand, the importances of all EEG indexes before the moving average are low. Therefore, we assumed that the accuracy may be improved by using LF, HF, LF/HF and EEG indexes after moving average as features. Therefore, we decided to use these indexes as features for model construction by machine learning in the next step.

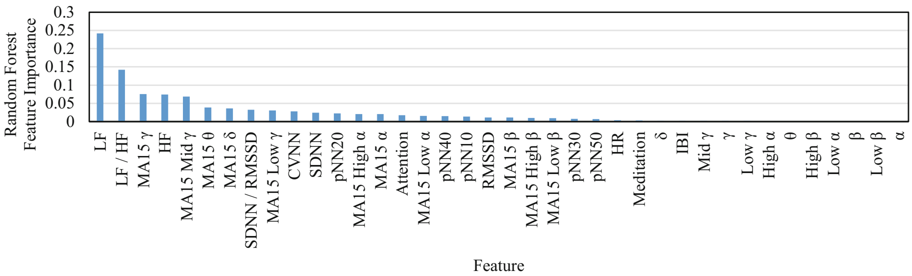

Fig. 3. Random forest feature importance

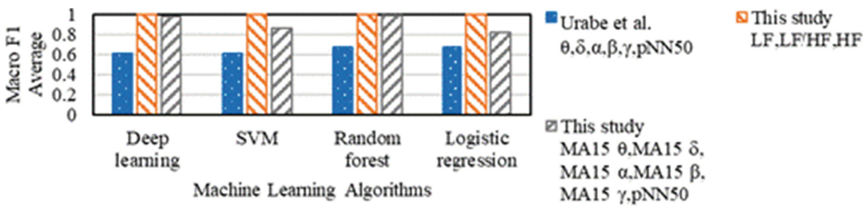

Fig. 4. Evaluation the accuracy of machine learning

5 Model Construction and Comparison of Accuracies

In order to investigate whether the accuracy can be improved, we constructed machine learning models with each of the indexes used by Urabe et al. and those based on the results of Sect. 4 and compare the accuracies. Urabe et al. used θ, δ, α, β, γ, and pNN50, and the accuracy is compared for the following two sets of features. The first set consists of the number of pairs of significant differences and the pairs of LF, HF, and LF/HF which were the indexes with high importances. The second set consists of MA15 θ, MA15 δ, MA15 α, MA15 β, MA15 γ, and pNN50, which are the post-moving-average EEG indexes instead of the pre-moving-average ones used by Urabe et al. The accuracies were averaged by stratified five-fold cross validation. Figure 4 shows the Accuracy of machine learning under the above settings. The machine learning structures are as follows.

- DL: Middle layer has 256 dimensions and 3 layers. Activation function is ReLU. Optimizer is Stochastic Gradient Descent (SGD).

- Random Forest: The number of decision trees is 1000. The index of impurity is Gini coefficient.
- Logistic Regression: Solver is LBFGS.
- SVM: Kernel is linear.

Figure 4 shows that the accuracies obtained from the models constructed by all the machine learning algorithms used in this study have been improved. In addition, when using LF, HF, and LF/HF, the accuracy was 100% for all of the algorithms. In the case of using EEG indexes after moving average, some of the machine learning algorithms improved the accuracy to nearly 100%.

6 Discussion and Future Work

We used music that was available in the music database and that we knew to some extent what kind of emotion it elicited. However, we were not able to elicit any emotions as expected. In addition, the number of data in the first, second, third, and fourth quadrants that were considered to have elicited emotions was uneven. As a countermeasure to this problem, we may ask the participants to decide in advance the music to arouse their emotions. By having the participants select the music that elicits their emotions and then play the selected one during the experiment, it will be difficult for the data to be biased even if the emotions elicited by the music differ from person to person. In fact, a study can successfully evoke emotions using the music selected by participants [21]. However, it is necessary to take into account that this method consumes the time which participants to choose the music.

The results of this study suggest that three indexes (i.e., LF, HF, LF/HF) can be used to estimate emotions in the first, second, and fourth quadrants of the Valence-Arousal space model. However, since this experiment was conducted with only one participant, the results were not very reliable. Our future work will increase the number of participants in the experiment and examine the EEG and HRV indexes again. In addition, since there is a possibility that the subjective evaluation may be inaccurate, we will consider unsupervised learning such as clustering without using the subjective evaluation and emotion estimation by reinforcement learning.

7 Conclusion

In this study, we performed experiment to collect data for calculating EEG and heart rate variability indexes. The indexes were then selected under the criteria to increase the accuracy of models to emotion estimation using statistical method as well as the importance of indexes obtained from machine learning. As the results, we succeeded to construct models with almost 100% accuracies by using DL, SVM, Random Forest, and logistic regression. In the future, we will improve our experimental method to collect more accurate data for model construction.

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An Analysis of the Cognitive Process and Similarities of Complex Problem Solving Discussions

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Abstract. The concept of complex problem solving (CPS) as a new cognitive scientific area was initially introduced by Doner 30 years ago. It was not until recently that the verdicts of CPS studies were gradually being applied in business training . This research aims to convert lab findings into light-weighted cognitive-oriented guidelines for CPS. To achieve this purpose, we investigated the pattern of the underlying cognitive process in CPS discussions. This paper proposes a method that compares cognitive similarities based on the Kolmogorov–Smirnov test. Instead of comparing the semantic similarity, this method compares the proportion of conversation content. It serves the purpose of examining the similarities of thinking processes. From the correlation between the subjective problem conflict level and cognitive similarities, we found that a discussion process best practice can help build a more comprehensive problem understanding.

Keywords: Cognitive process · Episodic memory · Semantic memory · Problem complexity

1 Introduction

A complex problem is a problem that has no clear definition of goals or solutions. Dörner et al. [1] defined the complex problem solving (CPS) process as a set of self-regulated cognitive processes necessary to achieve ill-defined goals that routine actions cannot attain in dynamic environments. Meetings occupy a large portion of time in many professions. They are one of the typical collaboration setups to solve complex problems. Nevertheless, it has been found that almost 50% of the ineffectiveness in meetings is caused by cognitive-related issues, such as information misrepresentation and inferior decision-making [2, 3]. Many researchers have tried to tackle this issue by studying action-wise facilitation in meetings. In the case of CPS, however, it is difficult to derive valid indicators of problem-solving performance for tasks that are not formally tractable and thus do not possess a mathematically optimal solution [4]. Therefore, we would like to adopt a different approach: formulate cognitive-oriented guidelines by identifying the cognitive process that optimizes the CPS discussion progress. Such

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progress is defined as the collaboration to apply sources to create outcomes. The sources refer to the information one possesses, while the outcomes mean the solution or problem interpretation.

In our previous work, we collected audio data from 16 experimental discussions from eight dyads, with a maximum duration of 30 min, and developed a coding scheme that unitized the discussions into source and outcome utterances. In this paper, we proposed a method that compares cognitive similarity based on the Kolmogorov–Smirnov test. Instead of comparing the semantic similarity, this method compares the proportion of conversation contents, which can serve the purpose of examining the similarities of thinking processes.

2 Methodology

2.1 Data Collection

In this research, we used a within-subjects design, with a mixed method of qualitative and quantitative analysis, including three questionnaires and one experimental discussion. The data collection methods are described in Table 1. To preserve the cognitive effort, participants were asked to discuss in their first language. Each dyad was asked to discuss two topics with different problem representations (series and parallel). The detailed procedure was introduced in our previous work [5, 6].

Table 1. Experiment design and execution procedure

Step	Content	Data to-be-collected
1	Questionnaire on problem difficulty and conflict (pre-discussion)	Solution; ratings of difficulty of each solution, conflict among solutions
2	Experimental discussion: problem-solving process	Two 30-min discussions: audio, video, and written data during the discussions
3	Questionnaire on problem difficulty and conflict (post-discussion)	Solution; ratings of difficulty, change in difficulty (Δd) of each solution, conflict among solutions, change in the conflict level (Δc); evaluation of previous discussions

2.2 Change in Subjective Difficulties and Conflict Level

The subjective problem difficulty and conflicts were evaluated through the questionnaire of problem difficulty and conflict [5, 6]. The influence of the discussion can be observed through the changes in the two values (Δd, Δc). The changes in the subjective difficulty and conflict level were calculated using Eqs. (1) and (2).

$$\text{Change in problem difficulty } (\Delta \text{d}) = d_{post-discussion} - d_{pre-discussion} \tag{1}$$

$$\text{Change in conflict level } (\Delta c) = c_{post-discussion}/c_{pre-discussion} \tag{2}$$

2.3 Comparing Problem Difficulty and Conflict

The comparison of the discussion between groups was performed through the values of changes in subjective difficulty and conflict level. As shown in Eqs. (3) and (4), to describe the relative magnitude, we used the absolute value of the difference and the multiple for the quotient.

$$\text{Difference in problem difficulty } \left(\Delta d_{A,B}\right) = |\Delta d_A - \Delta d_B| \tag{3}$$

$$\text{Quotient of conflict level } \left(\Delta c_{A,B}\right) = \max(\Delta c_A, \Delta c_B)/\min(\Delta c_A, \Delta c_B) \tag{4}$$

2.4 Unitizing and Coding

The audio data were first split by silences. Then, given that the working memory has a short duration of approximately 10 s [7], the audible parts were converted into utterances with a maximum period of 10 s with a one-second-precision. The collected audio data were then coded according to the scheme described in Table 2.

Table 2. Utterance coding scheme

Code	Sub-code
Source	Memory: episodic memory, semantic memory
	Cue: self-directed cue, other-directed cue
	Other: teamwork, Other
Outcome	Idea: initial idea, developed idea
	Problem representation: initial representation, interpreter

2.5 Cognitive Process

The cognitive process was examined by the ratio of utterance occurrence throughout the discussion. The ratio per minute was calculated using Eq. (5). To better display the tendency of the cognitive process, the ratio was aggregated using a 3-min unit.

$$\text{Ratio of occurrence for utterance } Type_j \text{ per minute} = \frac{\sum_{i=1}^{n}\left[u_i = Type_j\right]}{\sum_{i=1}^{n} u_i} \tag{5}$$

Where
$n =$ total utterance within the minute
$i =$ the i^{th} utterance
$Type_j \in$ {Episodic memory, Semantic memory, Self-directed cue, Other-directed cue, Teamwork, Other, Initial idea, Developed idea, Initial representation, Interpreter}
$j =$ the j^{th} utterance type.

2.6 Cognitive Process Similarity

The cognitive process similarity was derived by comparing the aggregated utterance occurrence ratio. The cognitive process similarity is the count of similar conversations from the entire discussion, as described in Eq. (6). The ratio was compared with the Kolmogorov–Smirnov test (KS test) [8], a nonparametric goodness-of-fit test that is used to determine whether two distributions differ, as described in Eq. (7).

$$\text{Cognitive similarity} = \frac{\sum_{i=1}^{k}[D_A(i)\ and\ D_B(i)\ are\ similar]}{k} \tag{6}$$

Where
$D_X(i) =$ the i^{th} aggregated minutes in the discussion X
$k =$ the count of total aggregated minutes in the discussion.

$$\mathrm{D_A(i)\ and\ D_B(i)\ are\ identified\ as\ similar\ if} \tag{7}$$

$$\sup_i |D_A(i) - D_B(i)| > \sqrt{\ln\left(\frac{\alpha}{2}\right) \cdot \frac{1}{2}} \cdot \sqrt{\frac{1}{n_A} + \frac{1}{n_B}}$$

Where
$\alpha =$ the critical value
$n_X =$ the count of utterance type that the discussion X is coded into.

3 Results

3.1 Participants' Information

We collected audio data from 16 experimental discussions from eight dyads (Chinese: 3, English: 1, Japanese: 1, mix of Chinese and Japanese: 2, mix of Chinese and English: 1). The selected participants were aged from 20 to 32, with a majority of Chinese Mandarin speakers.

3.2 Comparing Problem Difficulty and Conflict

Table 3 states the changes in subjective difficulty and conflict level per group. The Group 4 series discussion shows the highest values for changes while the Group 1 parallel discussion shows the lowest.

Table 3. Change in subjective difficulties and conflict level by group and problem types (s: series, p: parallel)

	1s	1p	2s	2p	3s	3p	4s	4p	5s	5p	6s	6p	7s	7p	8s	8p
Δd	-2	-1	3	10	-3	9	19	12	3	4	6	0	2	-9	0	5
Δc	0.13	0.33	13.5	0.5	2	0.25	4.5	4	1	0.5	2	1	4	1	0.5	0.5

3.3 Cognitive Process

The sum of the aggregated utterance ratios of the 16 discussions is shown in Fig. 1. Each column represents an utterance ratio of three minutes. The variety of content decreases throughout the discussion.

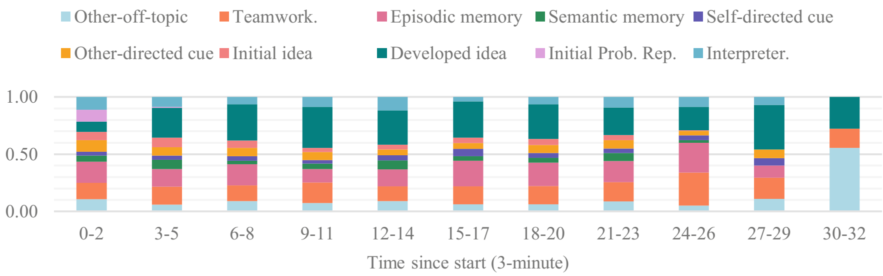

Fig. 1. The ratio of occurrence by utterance type. The discussion likely starts with problem definition (initial problem representation: 0.104) or recall of memory (episodic memory: 0.185). The ratio of the developed idea kept increasing until the 11^{th} minute (0.090, 0.261, 0.315, 0.359). The ratio of the off-topic discussion was significant (0.106) and exceptionally high (0.556) in the first and last three minutes, respectively.

3.4 Cognitive Similarity

As shown in Fig. 2, at $\alpha = 0.05$, with Eqs. (6) and (7) we were able to recognize the difference between discussions for 59 out of 120 comparisons. Group 3, series discussion and group 2, series discussion are the most and least similar to the rest of the sample, respectively.

3.5 Validation of Cognitive Similarity

Table 4 shows the correlation between cognitive similarities among discussions and the relative Δd and Δc between groups. The cognitive similarity shows a moderate negative correlation to the relative Δc with KS critical values (α) 0.01 and 0.05. However, it shows no relationship with the relative Δd.

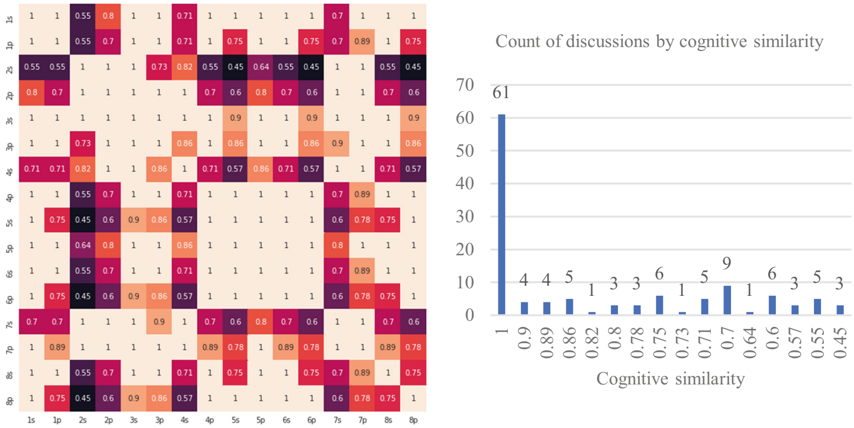

Fig. 2. The similarities among discussions with critical value α = 0.05. The highest similarity among the samples is "1" and the lowest similarity is "0.45". The two axes on the heatmap stand for the 16 discussions. For instance, "1 s" means group 1 series discussion. Each square in the heatmap stands for the cognitive similarity of two discussions. For example, the similarity between "group 1 series discussion" and "group 2 series discussion" is 0.55. The are 120 unique comparisons among the discussions.

Table 4. Correlation of relative Δd, Δc between groups and cognitive similarities with different KS critical values

KS critical value (α)	α = 0.01	α = 0.05	α = 0.10	α = 0.15	α = 0.2
Relative Δd	−0.114	0.001	−0.088	−0.088	−0.062
Relative Δc	−0.312	−0.324	−0.201	−0.201	−0.273

4 Discussion

The aggregated cognitive pattern shows that most of the problem definitions were completed in the first two minutes of the discussion. The initial ideas were mostly generated in the first nine minutes, while some ideas may be proposed in the first three minutes, then developed throughout the rest of the discussion. Little new content was generated from the 27th minute, and the conversation after the 30th minute was less likely to be helpful. From the perspective of facilitation, it is critical to build a shared understanding of problem representation and increase the number of solution options at the beginning of the discussion.

By comparing the changes in subjective difficulties and conflict levels among groups, as well as the values of cognitive similarities, we found that the cognitive pattern can influence the change in conflict level, which is related to the problem representation. Therefore, CPS discussion best practices can provide a better understanding of the problem breakdowns and intercorrelation. However, such best practices might not help reevaluate task difficulties.

The cognitive similarity can be a quantitative reference for discussion performance evaluation. Instead of comparing the semantic similarity, this method compares the proportion of conversation content. It serves the purpose of examining the similarities of thinking processes. However, the proposed cognitive similarity is not sufficiently sensitive for discussions with small differences in the outcomes. Future studies can re-examine the construction of cognitive similarity to increase its sensitivity and explore the indicators for the changes in subjective difficulties.

5 Conclusion

The purpose of this study was to formulate cognitive-oriented guidelines for solving complex problems within meetings. Based on the visualization of the aggregated ratio of utterance types, we found that the first 15 min in a discussion are the most productive. We proposed a method that identifies the cognitive process that optimizes the CPS discussion progress. The method compares cognitive similarities based on the Kolmogorov–Smirnov test. From the correlation between the subjective problem conflict level and cognitive similarities, we found that the cognitive similarity has a negative moderate correlation with the relative change in problem conflict. Therefore, best practices of the discussion process can help build a more comprehensive problem understanding. Future studies could consider re-examining the calculation of cognitive similarities to increase its sensitivity.

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Control Room Operators' Cognitive Strategies in Complex Troubleshooting

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Abstract. The aim of the present study was to investigate control room operators' troubleshooting performance and adaptive readiness in nuclear domain with a new version of a virtual reality control room (VR CR) system. The VR CR was a high fidelity copy of a physical CR. The test session consisted of five simulated incidents. Two operator crews were recruited. In addition, one separate crew participated in the pilot test. This paper focuses on analysis of individual process-tracing and debriefing interviews, performed after each simulator run. Our results showed that all the failures were successfully found and perceived with one exception. The operators were also able to formulate hypotheses about the cause of the failure and make plans on how to test a hypothesis and evaluate the evidence. On the other hand, the crews experienced some problems in problem monitoring and process control due to the problems caused by the VR system.

Keywords: Control room operator · Troubleshooting · Adaptive readiness · Simulated incident/accident · Virtual reality control room

1 Introduction

In many domains, professionals have to cope with demanding operating conditions. For example, firefighters and other first-responders face deadly dangers in disasters and other emergencies. In order to be able to manage emergencies and save lives the first-responders must be able to manage acute stress and extreme fear. To achieve the ability to cope with stress, they need readiness skills, such as adaptive expertise, problem solving, decision making, situation awareness and ability to work in a team.

The aim of the present study was to evaluate control room (CR) operators' troubleshooting performance and adaptive readiness in nuclear domain with a state-of-the-art version virtual reality control room (VR CR) system.

There is evidence that CR operators have problems in diagnosing complicated events and multiple simultaneous events in process industry. Even though there is a lot of research on troubleshooting in complex incident situations, there is a lack of knowledge of CR crews' adaptive strategies and activities in troubleshooting situations. In successful troubleshooting, after the problem has been identified, it is categorized, and a mental

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representation of the failure is constructed. Action retrieval stands for retrieving appropriate strategies for problem solving; in decision making a single action is selected from several options; and during outcome evaluation, the outcome and advancement of the problem solving process is assessed. Adaptive readiness in troubleshooting stands for the crew's ability to adjust their communication and collaborative processes, role-based relationships and performance strategies as the crew's operational environment changes.

2 Methods

2.1 Participants

Two operator crews (altogether six licensed operators) including two shift supervisors (SS), two reactor (RO) and two turbine (TO) operators participated in the study. In addition, one crew of three operators was recruited for the pilot test. All the participants signed an informed consent form before participating in the experiment.

2.2 Test Procedure

The test session consisted of five simulated incidents or accidents (duration varying between 10 to 40 min): 1) failed sensor measurement, 2) anticipated transient without scram (ATWS), 3) combination of two incidents caused by a mechanical error of a control valve and a hydrogen leakage, 4) loss of the BB bus bar, and 5) fire in the CR and transition to the Emergency Control Room (ECR).

After each test run, one simulator instructor evaluated crew performance on different factors such as process and alarm monitoring, process control, situational management, procedure usage and communication. In addition, the operators themselves evaluated their crew's performance after the simulated loss of the Main Control Room (MCR) accident.

2.3 Scenario Modelling

Functional situation models (FSM) were constructed for the analysis of the five simulated incident and accident scenarios. FSM combines two views, chronological and functional, which define a two-dimensional space in which the most critical operations and process events are mapped. Critical functions provide each action a contextual meaning, and the actions are inserted under the function to which they are related. In the chronological view, the incident is divided into phases based on the goals the operators are aimed to achieve; in the functional view, the critical functions, endangered in the incident, are depicted. In Fig. 1, a simplified version of a FSM is presented for the loss of MCR scenario.

2.4 Technical Set-Up

The VR CR was a high fidelity copy of a physical NPP CR. Apros®, a multifunctional software for modeling and simulation of NPP processes, was used in the creation of the

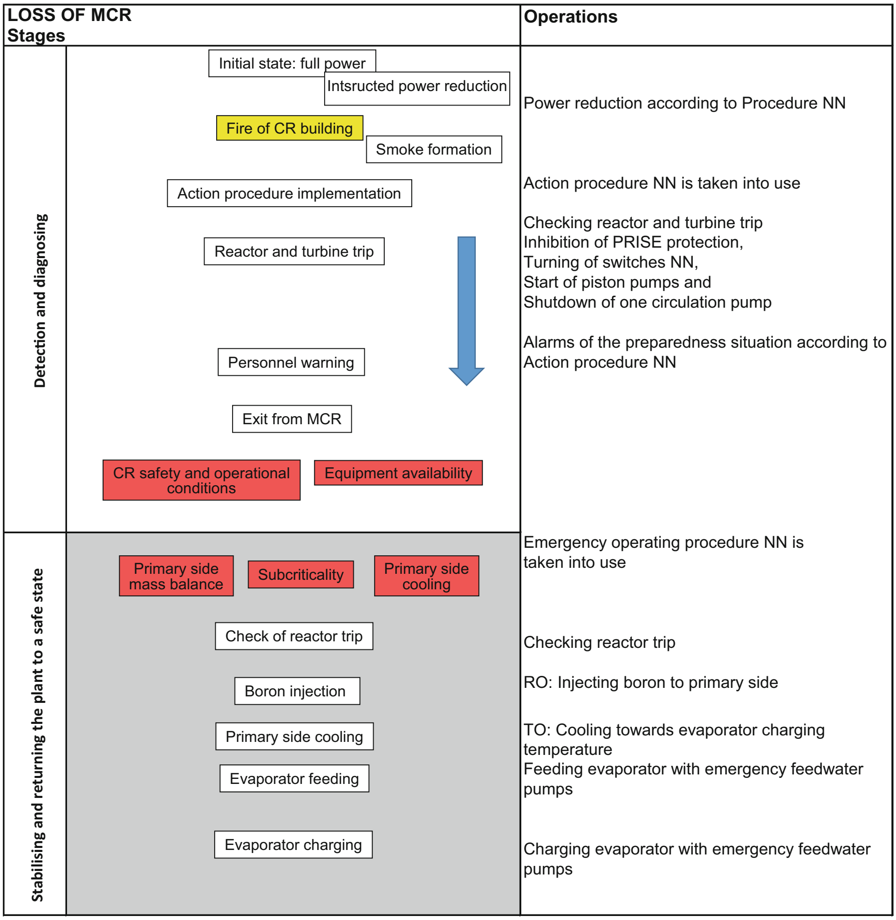

Fig. 1. Example of a functional situation model. NN stands for "Not Named".

scenarios; CR environments were, in turn, created by the Unity™ cross-platform engine [1]. Each operator's VR workstation comprised a computer with a high-end graphic card, a Varjo™ headset and Valve™ Index controllers [1]. An image from the physical test environment is shown in Fig. 2.

Every operator controlled their own avatar, and he used the controllers to move inside the virtual environment. Animations inside VR represent the operators' movements and actions in the virtual environment, and they also represent headset movements and rotations, making it possible to see what other operators were attending and doing. Data on the operators' movements and interactions with various objects were transmitted through a computer network to other operators and represented to them in real time. Control panels and desks were virtual touch screen displays operated by a virtual finger. Since the participants did not wear earphones, communication was real, not virtual. A more detailed description of the technical setup, test facilities and data recording can be found in [1].

Fig. 2. Example image from the physical test environment.

3 Results and Discussion

3.1 Expert Evaluation of Performance

Figure 3 shows the expert's evaluation of performance for the two crews. As can be seen, most of the scores are somewhat higher for one of the two crews. The differences were the largest for monitoring, control performance and procedure usage. Apparently, the differences in performance are mainly caused by possible differences in skills and knowledge in VR use.

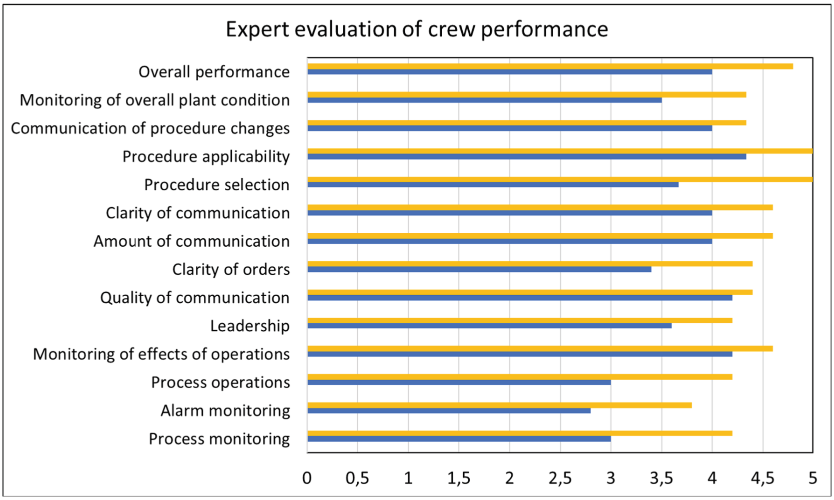

Fig. 3. Expert evaluation of crew performance for the two crews. Higher scores indicate better performance.

3.2 Subjective Evaluation of Performance

Figure 4 shows subjective evaluations of the crew's own performance. Operators were not very satisfied with their monitoring and control performance, and scores were higher for communication, collaboration, leadership and procedure usage. In general, shift supervisors were more satisfied with the crew's monitoring and control performance than the other two operators. Turbine operators' scores were somewhat lower for these dimensions. On the other hand, the TO's scores were higher than the other operators' scores for communication and leadership.

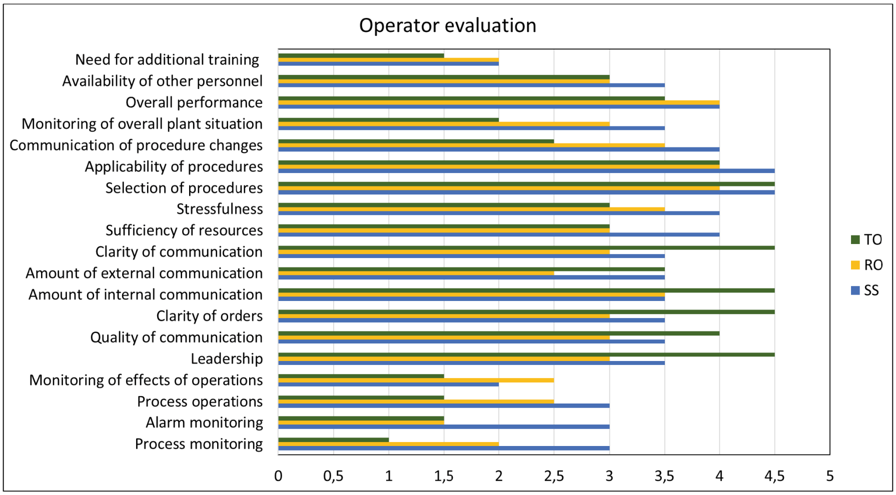

Fig. 4. Operator evaluations of the crew's own performance. The colored bars refer to the three operator roles. Higher scores indicate better performance.

3.3 Operator Interviews

According to the operator interviews, all of them had a quite good understanding of what had happened in each scenario and what they had to do. The problem that came about was that they were not always able to perform operations they would normally do in a physical CR. Next, we present the main findings of each simulator run.

Failed Sensor Measurement. An auxiliary pump motor stopped due to a measurement error, showing that the water level has decreased in the tank. In case of an emergency, the pump could no longer feed circulate water to the reactor. The key insight would be to understand that the pump was stopped due to a measurement failure, detectable from information presented on the Process Computer System (PCS). To rectify the situation, the operators should first change the water source to another tank, and secondly call the maintenance personnel to repair the fault. Both ROs were able to make all the critical observations and actions needed in this situation. They, however, felt that they would have performed faster in a physical simulator, because the number of PCS screens would have been higher, and consequently, more information could have been seen simultaneously.

ATWS. The simulator run started with the reactor operating on full power. After a while, the feed-water pumps were tripped, and the reactor and turbine trip were initiated. Reactor shutdown failed as the control rods got stuck in the upper position, and as a consequence, reactor power was set to 30%. Several operations are required by the anticipated transient without scram. First, the procedure for the loss of feed-water is applied, and second, the RO has to start the emergency boron injection system. Third, the electrical power is switched off so that the control rods can be manually operated and withdrawn.

Both crews had some difficulties in building accurate situational understanding, because the overview panel did not work, and changing the contents of PCS displays was cumbersome in VR. It was also somewhat unclear to ROs whether the Qualified Display System (QDS) system was working or not. One RO was not sure of whether the failed shutdown was real or whether it was caused by misinformation from the VR HMI. The other RO initiated reactor trip, but the control rods did not fall down. He conducted several observations and operations partly using the correct procedure, partly from memory. Because of this, the order of actions slightly differed from the order they are presented in the procedure. One RO noticed that the emergency boron injection did not start. He conducted manually some operations that would have been initiated automatically in a normal condition. Both ROs thought that the main difference to the conventional training was that performance was somewhat slower in VR than it would have been in the physical simulator.

Mechanical Control Valve Fault and Hydrogen Leakage. The simulator run started with an introduction informing the operators that the VC12 pump has an oil leak. The operators' task was to reduce power and stop the pump. Simultaneously, a mechanical fault occurred in a control valve. Therefore, the water level of a high-pressure pre-heater oscillated. As the water level exceeded a set threshold, an alarm was triggered, and the automation system separated the pre-heater group. The pre-heater group was stopped, resulting in reduced efficiency. After a while, a hydrogen leak occurred, requiring the operator to reduce electrical power.

One TO was not able to stop the VC12 pump on a virtual panel, but was able to do that on the PCS. Neither was he able to limit power along a desired gradient, and so he had to perform it in a different and more robust way. Perhaps because of these problems, the crew failed to identify the hydrogen leak. TO thought that in a physical simulator they would have detected the hydrogen leak on a panel or on a PCS display. Operators also reported that they had problems seeing clearly the information presented on a panel or desk from the operator workstation. One TO adjusted the power on the desired level so that the pump could be stopped. The operators noticed that the steam valves were closed, and the water level did not increase any longer.

Loss of BB Bus Bar. The starting condition of the fourth scenario was full power. Suddenly, one of the electricity bus bars went dead, and as a consequence, several pumps of the secondary side stopped, which compromised the mass balance. In order to prevent that, TO should throttle a three-way valve so that one of the RM pumps could be switched on. TO has about ten seconds to perform that, and in a physical simulator he is typically able to do that without problems, especially because the loss of the BB bus bar scenario has been trained several times in recent years.

Because rapid action is required in this scenario, the scenario was quite challenging for both crews in the VR CR. Since the TOs were not able to perform quickly enough, the pumps were tripped, and the crews had to limit power.

Loss of MCR. A sudden fire in the CR was introduced, forcing the crew to execute both the reactor and turbine scram and move to the ECP. Both crews were able to conduct all the critical operations in the MCR before leaving the CR. Since smoke was only visually simulated, the crews had some problems to decide when it is necessary to leave the CR. The crews failed to take along all procedures and other implements required by the procedure, at least partly due to difficulties in VR interaction. In the ECP, the SS of one of the two crews was not able to sign on the monitoring system, and therefore, instead of that, they monitored the process on a PCS display.

Summary. Both crews were able to perform well, and they were able to detect and identify all the faults apart from one. They were also able to carry out all the critical operations to stabilize the process. However, performance was slower than in a physical simulator, and none of the two crews was able to perform the critical actions fast enough in the loss of the electricity bus-bar run to prevent the pumps from stopping. The order of actions was also sometimes different from the order presented in procedures, and the information they needed was observed from another source than is typically used. In addition, in order to produce a particular effect on the process, alternative operative means were sometimes applied. The latter point indicates that the crews were able to represent flexibility and adaptability characteristic to behavioral resilience. Some other signs of adaptive readiness were also identified in interviews:

- Operators helped each other by delivering information the other operator needed in a particular situation.
- An operator requiring particular information walked to another operator's workstation to check that information.
- Operators were able to coordinate and orchestrate activities with each other by deciding beforehand who monitors which information and by agreeing on the order in which RO and TO conduct their operations on the ECP.
- Before the start of an incident, an operator walked around the VR CR and checked what procedures are available on a table so that after the incident has launched, he could immediately find the procedure he needed.

3.4 Debriefing

Debriefing discussions focused on the main deficits of the VR CR giving insight on what information sources and operative systems are the most critical to operator work:

- The operators thought that the number of PCS displays should be large enough so that all the critical information can be monitored simultaneously. In general, all operators should have all the displays they have in a physical CR. For example, the SS hoped he would have the QDS display on which he could monitor all the critical information of the reactor side. Operation of the PCS displays should be effortless enough: since mouse operations could not be performed fluently, touch screen operation would be a better alternative. It is important that an operator is able to easily observe the information on panels and desks from the workstation. Since this was not the case, some kind of panel zoom would be useful to bring the information closer to him/her.

- It is important that the PCS screens of an operator workstation are located in such a way that the operator is facing the large screen display, when he/she is looking at the PCS displays so that there is no need to turn his/her head.
- In a physical CR, the operators have learned to hold the procedure in their hand and put it aside if needed in a flexible way. In a VR CR new ways of holding a procedure must be learned which takes time and introduce errors.
- In our study, the operators were totally dependent on visual information, which may have deteriorated performance in the early stages of a simulator run. Cues in other modalities, and especially sounds, play an important role in operator situation awareness. Especially, alarm sounds are important in the beginning phase of an incident in the detection and diagnosis of a fault.
- The avatars of different operators had a standardized frame and face, making it difficult to recognize other operators. If an operator is standing in front of another operator, it is difficult for him/her know which one to speak to.
- Skillful performance in a CR is based on a versatile set of observations and actions, which are partly reflexive and unconscious, partly conscious and deliberate. Virtual simulations should address all the behaviors and offer means to either replicate them in VR or provide an intuitive alternative to them.

4 Conclusion

Our results show that all the failures were successfully found and perceived with one exception. The operators were also able to formulate hypotheses about the cause of the failure and make plans on how to test a hypothesis and evaluate the evidence. On the other hand, the current VR CR implementation still has a number of issues with mediated and simulated controls, managing peripheral objects, and visualizing information readily available in the real-world equivalent. These presented the crews with additional challenges in monitoring and controlling the nuclear process.

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Cognitive Interventions Based on Technology: A Systematic Literature Review

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Abstract. This article reports a systematic review of research done about the positive impact of cognitive treatment for people with some type of brain disorder through the use of inclusive technologies. The article collected 21 publications of high impact magazines uncovering that countries such as Spain, France, and Russia have a significant number of contributions on this topic. Inclusive technological innovations which are intended for work on brain functions such as attention, memory, verbal fluency, problem-solving and behavior regulation have been mainly developed in devices such as Tablets and Robots. The data discussed highlights the need to continue in this line of research to determine the effect of this type of intervention, as well as the future projection of developing new technological devices facilitating human brain functions.

Keyword: Systematic review · Cognitive treatment · Inclusion · Technological innovation

1 Introduction

The current accelerated technology development offers a wide range of possibilities related to its use to benefit human disabilities. Also, countries around the world are researching ways of applying technology to treat different cognitive difficulties such as attention, memory, social abilities, verbal fluency, among other important cognitive functions in the context of disability [1–3].

Among the different technological devices available, tablets, smartphones, and robots stand out. These devices combined with apps and diverse existing programs [4] have made it easier to help people with disorders such as autism, dyslexia and other verbal

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skills [4, 5]. Additionally, the educational field researches methodologies to enhance the use of technology for the benefit of learning [6, 7].

Therefore, in the described context arises a research question: What technological developments have been proposed for cognitive intervention in favor of people with brain disorders? To answer this question, articles published on this subject were reviewed from the main databases.

2 Method

This study was based on a systematic literature review methodology [8]. Two processes were developed: (a) first, the identification and selection of the studies to be analyzed and (b) second, the design of the protocols that allowed the extraction of the information from the selected studies to answer the objectives of this work.

2.1 Analyzing Process for the Information Included from Studies

The study was divided into the following phases: (a) inclusion criteria of the studies, in which the articles were extracted from the Web of Science and Scopus databases, published between 2009 and 2020 (search end date: March 1, 2020), with keywords: technological developments for cognitive stimulation. The studies' language could be in English, Spanish or Portuguese. Two iterations were performed, that is, two different searches combining the respective keywords and filters against each database. Duplicate stage: repeated studies were removed. Repetition steamed from the existence of the study in both databases or due to the iterations carried out. Eligibility stage: studies without the search keywords neither in the title nor abstract and those that did not respond to the objective of this review, were removed altogether. Selection stage: the studies were downloaded to make a comprehensive reading of the manuscript applying the exclusion criteria corresponding to technological intervention investigations in favor of cognitive functions. Bias stage: the entire process was reviewed by two independent reviewers**.**

3 Results

3.1 Sample Size

These technological intervention studies showed that the most common frequency in total participants is from 21 to 30. Table 1 shows the sample size range, item identification, and their respective percentage.

Table 1. Sample size range of students participating in the studies analyzed

Sample Size	Article ID	Percentage
1 TO 10	11, 15, 23, 27	19.04%
11 TO 20	13, 21, 24, 29	19.04%
21 TO 30	17, 19, 20, 28, 30	23.84%
31 TO 40	18	5%
41 TO 50	16, 26	9.52%
51 TO 100	12, 25	9.52%
100 TO 200	14	4.76%
MORE THAN 300	22, 15	9.52%

3.2 Participant's Countries

This review found that Spain, France, and Russia are the countries that have made a great contribution to the research of technological development in favor of the treatment of cognitive difficulties. Figure 1 shows the countries where the selected studies were conducted.

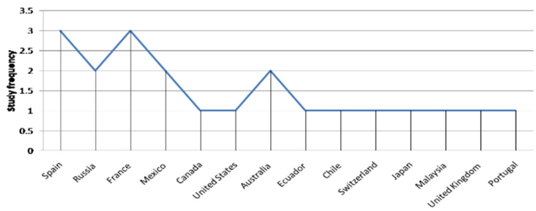

Fig. 1. Graphic representation of countries where the studies were done.

3.3 Education Level

Regarding the educational level of the participants in the different researches, it was shown that most of the studies seek to intervene in several of them. Figure 2 shows this data.

3.4 Technological Intervention Protocols

The review identified various types of cutting-edge technological innovations for smartphones, tablets, PCs, robots, serious games, applications for TV and others. The development of these devices was aimed at improving learning processes, behavioral control,

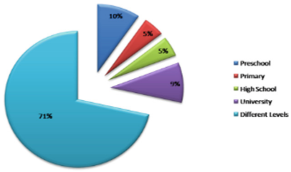

Fig. 2. Graphic representation of the interventions according to the educational level

emotional regulation, sensory stimulation, cognitive development, higher mental functions, time organization, support in motor treatment, personal self-care and other benefits for the individual. Figure 3 shows the distribution percentage according to the type of device.

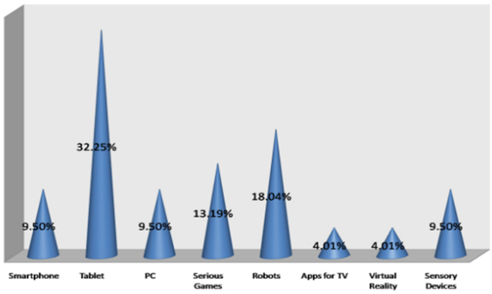

Fig. 3. Graphical representation of technology developed in favor of cognitive stimulation

3.5 Integration of Analyzed Information

The studies reviewed revealed an interest in inclusivity from a technological development standpoint, which has provided attention in the treatment of cognitive disorders present in disorders resulting from human brain dysfunction. In the data analysis, it was possible to identify 6 communities formed among the 14 countries that share nodes such as the time of intervention, the cognitive function intervened, and the type of technological device used. Figure 4 presents a representation of the interaction of the key variables of each analyzed study and the identified communities differentiated by color. The identified communities have high modularity since they have solid connections between the nodes [9].

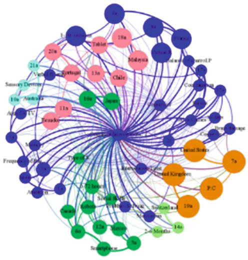

Fig. 4. Graph that includes the interaction of the variables extracted in the research and identified communities.

4 Conclusions

This paper reports the data uncovered after a systematic review of the literature on inclusive cognitive research based on technology in favor of people with brain disorders. To answer the research question, what technological developments have been proposed for cognitive intervention in favor of people with brain disorders, 21 articles from 14 countries located in Web of Science and Scopus databases were selected.

After the data was extracted and processed, the following results were obtained: Spain, France, and Russia are the countries with the highest number of contributions in technological development research in favor of cognitive difficulties. The studies analyzed are focused on similar proportions at all educational levels from preschool to university. Concerning intervention protocols, tablets are the most used resource, followed by robots and other devices. Regarding cognitive functions, the analyzed studies focused its interventions on improving attention, memory, verbal fluency, problem-solving, behavior regulation, among others.

Finally, to identify the interaction between the variables, a network analysis was applied, resulting in the identification of six communities between the participating countries, which shared solid connections between nodes, such as the intervention device, the cognitive ability treated, and the intervention time. The results found in this research are consistent with previous systematic review studies, such as Portuguez [10] and Pellas, Kazanidis and Palaigeorgiou [11].

The next step in this research line is to perform a meta-analysis study. The research team will analyze the standard values of the effects of interventions and determine the most effective technological devices to intervene in the cognitive treatment of brain disorders.

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Exploring Relationships Between Distractibility and Eye Tracking During Online Learning

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Abstract. More than half of students think their attention is easily shifted when they're learning online. Distractibility, to a certain extent caused by visual stimuli is the main impact to decrease their academic performance. In addition, eye-tracking technology has been widely applied to explore distractibility in many "look" tasks, such as reading, viewing advertisements, and watching online videos as well as measure the efficiency of visual cognition. Therefore, this paper aimed to discuss the relationship between distractibility with eye movement indices and academic performance. Fifty high school students (30 girls) were recruited to complete experiment that was divided into two groups, which are the experimental group with distractions and controls with no one. The result showed that three of traditional eye movement indices were significantly correlated with distractibility ($p < 0.05$). Then we introduced the network accessibility model and the gaze transformation entropy to create two composite indexes according to the complexity and directivity of distractibility characteristics. The result revealed that the two composite indexes are significantly correlated with distractibility ($p < 0.05$). Finally, we constructed the mapping model about eye movement metrics about distractibility and online learning performance with a machine learning algorithm. The result ration was $R^2 = 0.799$, and the error was $Re < 0.1$, which proved the model was feasible and accessible. The research from the perspective of distractibility can provide valuable support for physiological indicators testing tools of academic performance and highlights the applications of eye movement dynamics.

Keywords: Eye tracking · Interactive design · Online learning · Entropy · Distractibility · Machine learning algorithm

1 Introduction

Due to the impact of the COVID-19 pandemic [1] on face-to-face learning, Ministry of Education of the People's Republic of China issued the policy of "suspended class, ongoing learning", spurring a surge in online streaming in China up to 69.9% in the first half of 2020[1]. In the first quarter, the whole eLearning market reached RMB 68.6

[1] Ministry of education of the people's Republic of China, "suspended class, ongoing learning" [EB/OL]. (2020-01-29) [2020-03-30]. http://www.moe.gov.cn/jybxwfb/gzdtgzdt/s5987/202001/t20200129416993.html.

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https://doi.org/10.1007/978-3-030-80285-1_31

billion[2]. Moreover, compared with the increasing demand of eLearning market, learning experience is not satisfying in the case of learners' academic performance that do not so well because of too many distractions like social media, pop-ups, and information overload. Actually, more than half of students think their attention is easily shifted when they're learning online [2]. Distractibility, to a certain extent caused by visual stimuli [3, 4], is the main impact to decrease their academic performance [5].

In addition, eye-tracking technology has been widely applied to explore distractibility in many "look" tasks, such as reading, viewing advertisements, and watching online videos [6–8] as well as measure the efficiency of visual cognition [9–12]. Applying eye-tracking methodology to explore learner's visual attention distribution while navigating an online learning interface is not a completely new idea. Wang analyzed the relationship between eLearning interface design and distractibility through eye-tracking technology [13]. By using eye-tracking technology to examine students' visual attention while solving multiple-choice questions, Tsai thought that this technology can be adopted to explore the cognitive process of online learning as well as an online assessment system [14]. With the aim at understanding learners' attention and behaviors, Mu et al. scrutinized the learning process in online education by eye-tracking technology [15]. However, previous studies have focused mainly on the traditional eye movement indices on temporal and count scale [16] like fixation duration and fixation count in quantitative analysis. As a matter of fact, these traditional indices would be influenced by other factors in addition to distractions. For instance, fixation duration is not only affected by task difficulties [17] but also cognition load [18]. Overall, it's not enough to analysis the relationship between the traditional eye movement indices and distractibility.

Therefore, this paper introduces the network accessibility model [19] and the entropy of gaze transition [20] to create composite indexes from the perspective of distractibility characteristics. The result shows that composite indexes are significantly correlated with distractibility ($p < 0.05$), which is further examined the mathematical relations along with other eye movements indices. (See footnote 1)

2 Related Work

2.1 Network Accessibility Model

The theory of network accessibility comes from transportation system [19]. To date the research on network accessibility has become a multidisciplinary topic. Accessibility means the ability to be reached. Spatial accessibility implies the various forms of distance from one point to another. Each point, which can be considered as a transfer station, a supply center, or even a virtual server address, is connected each other to transfer resource or information from one point to another, which constitute a network with topological structure [21–23]. Likewise, each fixation point can serve as a point in the network and each saccade path with spatiotemporal pattern connects two fixation points, which means eye path is transferred from one place to another. Eye path that transfers from the learning area to distracted area can be captured by eye tracking technology, which forms

[2] Iresearch. 2020Q1&2020Q2eChina online education market data release report [EB/OL]. (2020-06-29) [2020-06-29]. http://report.iresearch.cn/report_pdf.aspx?id=3599.

the topological structure. Therefore, we aim to address the quantitation of distractibility with the theory of network accessibility.

2.2 Entropy and Eye Movements

Most naturally-occurring phenomena are nonlinear with the characteristics of complexity and randomness. Entropy, which is coined by Rudolph Clausius [24], specially, is applied to measure the state of disorder and uncertainty. Applying entropy to analysis of eye movements is not a completely new idea. It was likely the first introduced by Tole et al. to quantify gaze points with Markov chain [25, 26]. Then the theory was gradually leveraged by many researchers to describe the uncertainty and complexity of underlying system in the field of visual perception. For instance, Harezlak et al. applied approximate entropy to analysis eye movements, which tried to describe eye movement dynamics [27]. Then he followed suite and observed eye movement signal characteristics, including fixation, saccade and saccade latency, with approximate entropy, fuzzy entropy, and the Largest Lyapunov Exponent [28]. Besides, eye path could move to any areas, not only the distracted area, in the screen when the learner is distracted by visual stimulus, which means eye path is complexity and disorder. Hence, we will discuss the distractibility with the theory of entropy.

3 Hypothesis

Previous research on distractibility has emphasized the impacts of visual cognition with a series of experiments. For example, Amador et al. assessed visual attention through the measurement of fixations in a binocular rivalry task in children with Attention deficit hyperactivity disorder (ADHA) [29]. ADAMS found that subjects with ADHD displayed more saccade than did controls [30]. Hutton et al. provided insight into how people in different mental status reflected to tasks with "distraction" [31]. Chen's exploration about distractibility and attention distribution of children with autism spectrum disorder was supported by eye-tracking and computer-aided technology [32]. In other words, the exploration that visual attention in eye-tracking experiment accurately shows that the cognitive processing [10] can well support eLearning research.

Besides, distractibility that is defined as divides attention, split attention, is spatially noncontiguous [33]. In other word, characteristics of distractibility are spatiality and discontinuity. Normally, the direction, flowing from the areas of interest to other, of eye path is predictable in the screen during online learning. When a distraction, for example, pop-ups, appears in the visual field suddenly, learner's attention would be forced to be distracted and his/her eye path would unconsciously leave the current AOIs to other areas. Which areas it would move to cannot be sure, maybe to the area of pop-ups or other area. Thus, the characteristics of eye movements would be complexity but still maintain a certain directionality. Overall, from the above analysis, we hypothesize the following:

H1: Eye movements reflect the distractibility of online learning interface.

H2: The directionality and complexity of eye movements are the two main factors of distractibility.
H3: Distractibility can be quantified with eye movement indices.

4 Method

4.1 Equipment and Materials

We used Tobii x3-120 to present the experimental materials and track subjects' eye movement. The screen resolution ratio is 1680 × 1080 px, and the sampling frequency is 300 Hz. The operating distance between the eye tracker and subjects is 50–80 cm.

The switch calculation between binary and octal, hexadecimal is served as online learning task. The value of academic performance is equal to the number of correct responses divided by the record time. The exam in each group has four questions. The resolution ratio is 1680 px × 1050 px, which ensures full screen display in Tobii studio.

4.2 Subjects and Procedure

We recruited 50 high school students to participate in the experiment. There were 20 boys and 30 girls with normal vision, between 14 and 19 years old. Before the experiment, subjects have to complete a questionnaire survey about their experiences to guarantee the effectiveness of the following experiment.

The project was designed with 2 (distracted factors: no distracted factor D0, a distracted factor D1) × 1 (Test T1). The process was as followed:

There're two groups in the experiment, which the group with pop-ups serves as distracted group while the other without distraction serves as controls. Let subjects read the introduction of the experiment to make them understand that the task of the experiment; then press any key to enter the waiting page, waiting for 500ms; next, enter into the learning page automatically. The subject would watch a video about the binary of computing, which would teach you how to calculate, for 1 min. After that, enter into the examination to complete 10 exercises and we do the timekeeping. The final score is the correct number of answers divided by the time they spent. Each subject has to finish the task of distracted group. Then he/she would take 10-min break to finish the task of controls. The experimental process is as followed in Fig. 1.

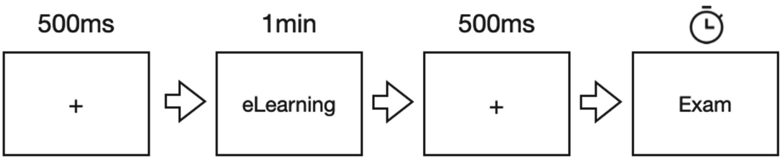

Fig. 1. Experiment process

5 Results

5.1 Traditional Statistical Indices

The traditional statistical indices, including pupil diameter, fixation duration, fixation count as well as saccade duration, which could be obtained directly with eye-tracking technology. The regression path time rate (RPTR) [34] need to be calculated by the following formula:

$$RTR = T_r/T_f \quad (1)$$

where T_r is total regressive duration, T_f is total fixation duration. Regressive duration is the time of looking at the same fixation point again, which can be obtained by the coordinate position of the fixation point.

By subtracting the eye movement indices in the experimental group and the controls, we got distracted factors, denoted as 'Δ' (Table 1, where ΔPD, ΔFD, ΔFC, ΔSDR, ΔRTR, respectively, is the difference of eye movement indices, including pupil diameter, fixation duration, fixation count, saccade duration ratio, and regression time ratio, between the distracted group and controls). Each index has no significant linear correlation value with the academic performance. The results show that three of the indices, pupil diameter, saccade duration, as well as regression time ratio have weak negative correlations with academic performance ($P < 0.05$).

Table 1. The correlations of some traditional statistical indices: ΔPD, ΔFD, ΔFC, ΔSDR, ΔRTR.

	Pearson correlation	Sig.	Two-class ANOVA F-value	Sig.
ΔPD	−0.366	0.041	3.1794	0.0125
ΔFD	−0.127	0.665	0.2158	0.8759
ΔFC	−0.285	0.324	4.3614	0.4932
ΔSDR	−0.374	0.017	1.8252	0.0375
ΔRTR	−0.357	0.034	0.4496	0.0418

Note: Three variables, ΔPD, ΔSDR, and ΔRTR, are correlated with academic performance. They are also significant with the Two-class ANOVA. RTR is regressive time ratio, SDR is saccade duration ratio, *PD* is pupil diameter, FD is fixation duration, FC is fixation count

5.2 The Complexity of Eye Movements

Obviously, these three indices, including pupil diameter, saccade duration, and regression time ratio, have not significant linear correlation with academic performance because of being affected by other factors in addition to distractions. For instance, regression time ratio is not only affected by distractibility, but also task difficulties [17] and cognition load [18]. Overall, it's not enough to analysis the relationship between the traditional eye movement indices and distractibility.

Eye tracker records the line of sight from one place to another. It is a vector with timeline, shown as in Fig. 2. In the distracted group, there're two AOIs in the screen, where AOI1 is the learning area, AOI2 is the distracted area. Eye path transferred between the two areas (see Fig. 2).

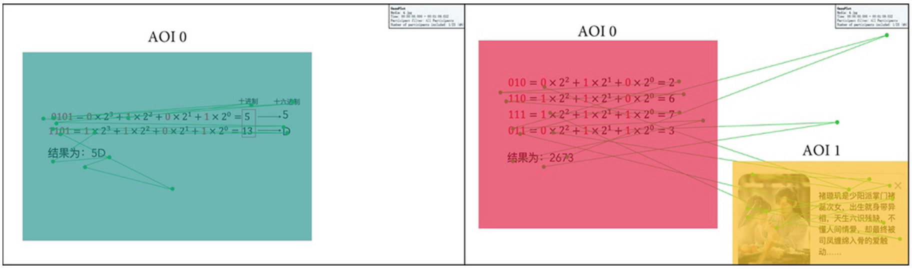

Fig. 2. Eye tracking. In this picture, we can see the participant's eye path. Each dot is a fixation point. The number is a fixation sequence. Left is controls, right is the distracted group. Figure 2 is the screenshot of one subject's eye path in two experiment groups.

Gaze plot is mainly about the saccade path. The cognitive efficiency and processing difficulty can be reflected by the directionality and complexity of the saccade path [33]. And it had been demonstrated that these two aspects, including cognitive efficiency and processing difficulty, have an effect on distractibility [33]. Therefore, we decided to discuss the saccade tracking from these two aspects. About the directivity of saccade tracking, we introduced Maćkiewicz's network accessibility model [19], which it can be used in the study on the directionality of saccade path. Accessibility can be reflected on the degree of difficulty in completing activities. It is the interaction between spatial locations. The path can be simplified as the topological relationship of the main viewpoint, and the saccade path can be reflected by the accessibility. The formula is as follows:

$$A_i = N_{ti}/N_{ri} \tag{2}$$

$$R = \frac{1}{n}\sum_{i=1}^{n} A_i \tag{3}$$

where R is accessibility, N_{ti} is the measured accessibility in area i, which is the number of gaze directions to other regions after the sight leaving this area, N_{ri} is the accessible amount of area i, which is the number of other areas accessible from this area, i is one of AOI, and n is the number of AOI [19].

We introduced Gu's gaze transformation entropy model [20] to study the complexity of saccade path. Gaze transformation entropy is based on the principle of Shannon entropy to study the complexity and uncertainty of gaze path. The formula is as follows:

$$H = P(0)\sum_{i \neq 0} p_{i0} \log_2(p_{i0}) \tag{4}$$

where H is the gaze transformation entropy, p_{ij} is the probability from the target AOI i to the unrelated area—*AOI 0*. $P(0)$ is the probability of focusing point in *AOI 0,* which can be obtained by counting fixation points in *AOI 0.*

In this way, we studied the saccade path from its directionality and complexity, and got two eye movement indicators–accessibility and gaze transformation entropy, which made the evaluation indicators of interference effect more integrated.

By subtracting the eye movement indices in experimental group and the controls, we got distracted factors, denoted as 'Δ' (Table 2, where ΔR *and* ΔH, respectively, is the difference of eye movement indices, including accessibility and gaze transformation entropy, between the experimental group and controls). The results of the analysis are listed in Table 2. The results show that the two indices, accessibility, and gaze transformation entropy have weak negative correlations with academic performance ($P < 0.05$).

Table 2. The correlation of directivity and complexity of eye path: ΔR, ΔH

	Pearson correlation	Sig.	Two-class ANOVA F-value	Sig.
ΔR	−0.379	0.015	1.4453	0.0217
ΔH	−0.561	0.028	2.3741	0.0365

Note: Two variables, ΔR and ΔH are correlated with academic performance. They are also significant with the Two-class ANOVA. R is accessibility, H is gaze transformation entropy

6 Discussion and Conclusion

In the case of the distracted factor as the only variable, we can take the difference of eye movement indices between the experimental group and the controls, which can be expressed by the following formula:

$$DE = \Delta EI(RTR, SDR, R, H, PD) \quad (5)$$

where DE is distractibility, EI is eye movement indices, RTR is regressive time ratio, SDR is saccade duration ratio, R is accessibility, H is gaze transformation entropy, and PD is pupil diameter.

As the eye track indices have no significant linear correlation with academic performance, we introduce a machine learning algorithm—back propagation (BP) neural network algorithm to construct the mathematic model with these indices and academic performance. The structure of BP neural network algorithm was as followed in Fig. 3. It divides with three layers: input layer, hidden layer and output layer.

These indices of distractibility contained five variable parameters, so the number of neuron nodes in input layer is five. The online learning performance is determined by five indices, so there is one neuron in the output layer. According to the empirical

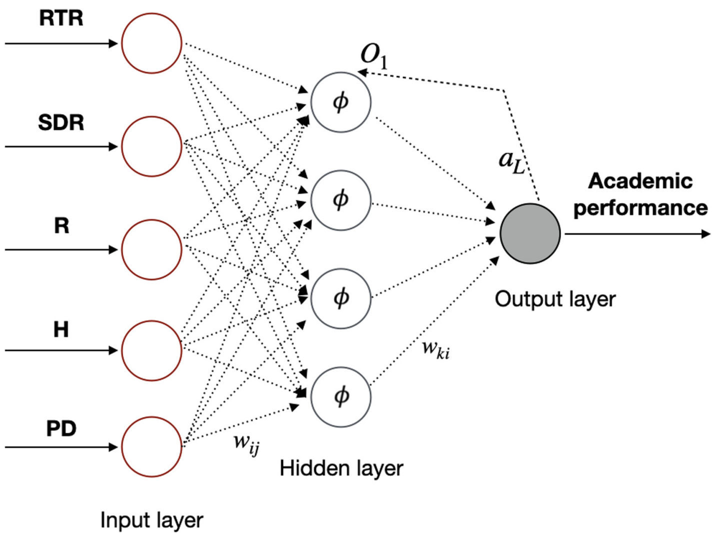

Fig. 3. BP network model. There're five neurons in the input layer, which represent regressive time ratio, saccade duration ratio, accessibility, gaze transformation entropy, and pupil diameter. According to the empirical function, there're four neurons in the hidden layer.

formula, the node number in hidden layer is four. The transfer function is logarithmic-S type:

$$f(x) = \frac{1}{1 + e^{-x}} \tag{6}$$

The first 40 samples are training set, and 10 samples are testing set. The learning times of the network is 500 times, the error is set at 0.01. When network training run 17 times, it reaches the training goal and stop training. The results of MATLAB network training are shown in Fig. 4, 5:

In order to verify the reliability of the converged BP neural network, we verified the relative error of the model.

The relative error formula function is used to analyze.

$$Re = \frac{\sum |DE - DE_0|}{n} \tag{7}$$

where DE is the learning prediction performance of the model, DE_0 is the actual learning performance. The demerit of error analysis is as followed in Table 3.

The research constructed and empirically explored the model, which we demonstrated the relationship between distractibility and learning performance from the visual cognition with eye movements (binary transformation algorithm).

In order to discuss the relationship between distractibility and academic performance, we used eye tracking technology to collect more accurate and objective visual data, including saccade duration, fixation duration, fixation point counts, saccade path and pupil diameter, etc. Chang believed that fixation duration, fixation point count and

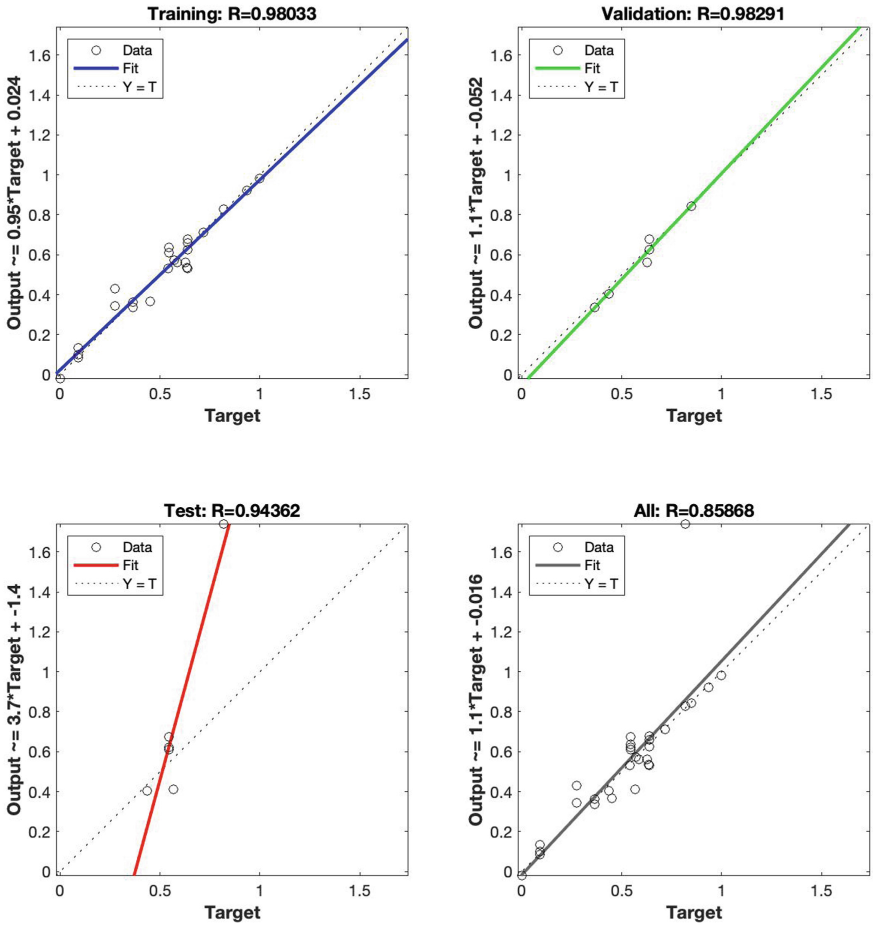

Fig. 4. Plot liner regression. Top left: training set, fit degree is accessible (R = 0.980 > 0.8). Top right: validation set, fit degree is accessible (R = 0.983 > 0.8). Bottom left: test set, fit degree is accessible (R = 0.944 > 0.8). Bottom right: fit degree of training, validation and test, fit degree is accessible (R = 0.859 > 0.8)

saccade duration could be reflected users' attention [34]. Table 1, 2 show some composite indexes, including ΔPD, ΔRTR, ΔSDR, ΔR, ΔH, which "Δ" represents the difference of eye movement indices between the experimental group and the controls, are correlated with academic performance ($p < 0.05$), which support the hypothesis 1. In addition, each index has no linear correlation value with academic performance ($|r| < 0.5$).

The distractibility is also related to eye path, which is produced by overt attention [34]. ΔR, ΔH represent the difference of accessibility and gaze transformation entropy between the two experiment groups, which accessibility is about directivity of eye path, while gaze transformation entropy is about complexity and randomness of eye path. Table 2 shows the two indexes about directivity and complexity are correlated with academic

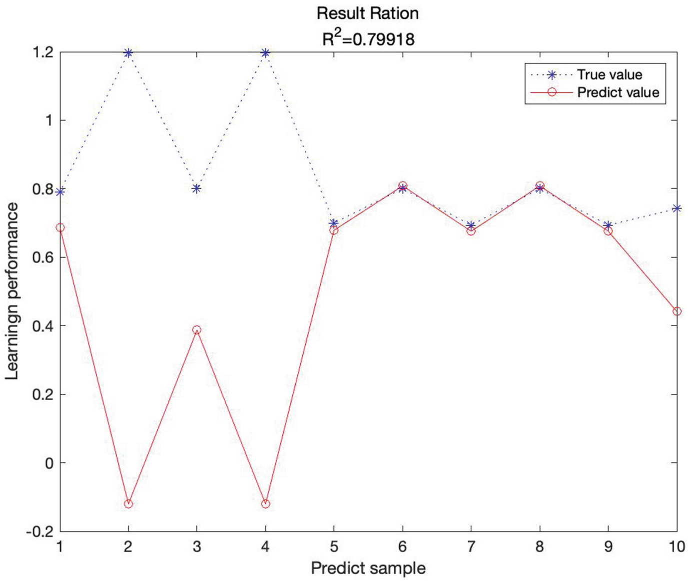

Fig. 5. Plot result. Result ration reached 0.799, closed to 0.8

Table 3. Error analysis

Target	Validation	Re
0.7905	0.7777	0.0428
0.5	0.5309	0.0618
0.7	0.7607	0.0724
0.8	0.8553	0.0691
0.7246	0.7858	0.0844
0.5775	0.5756	0.0031
0.7958	0.7542	0.0523
1.0309	0.9601	0.0687
1	1.0063	0.0063
1	0.9372	0.0628

performance ($p < 0.05$), which distractibility is considered as mediatory. This supports the hypothesis 2.

Because of the directionality and complexity of gaze path, we provided insight into saccade path from directionality and complexity by introducing gaze transformation entropy model [20] and network accessibility model [19]. Through the in-depth study of saccade path, we further optimized and improved the eye movement indices related about distractibility.

The composite indexes that are significantly related with distractibility serve as the independent variables, while the academic achievement serves as the dependent variable to construct the model with back propagation neural network algorithm. It divides the raw data set into two parts: training set with 40 samples and test set with 10 samples. Set 500 times to train. Finally, the overall error rate $Re < 0.1$ within the acceptable range. It implies that the model is feasible to evaluate the online learning performance with the composite index, including ΔPD, ΔSDR, ΔRTR, ΔH, *and* ΔR, that are related to the distractibility, which supports the hypothesis 3.

This paper conducted eye-tracking experiments to analyse the link between distractibility and interface design with eye movement metrics which combine the traditional indices with composite indexes with the network accessibility theory and gaze transformation entropy based on the complexity and directivity of distractibility characteristics, which can provide valuable support for physiological measurement techniques of academic performance and highlights the applications of eye movement dynamics.

In fact, task execution requires not only visual perception but also hearing, haptics, or a combination of multiple senses [33]. However, in the experiment, we mainly focused on the impacts of visual perception but dismissed other senses. Therefore, we can propose future studies that can shed light into the link between multimodal integration and academic performance to evaluate platforms.

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Human–Machine interaction and Learning Systems

Designing Augmented Reality Learning Systems with Real-Time Tracking Sensors

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Abstract. This study aims to develop an advanced augmented reality (AR) system by integrating an AR system and a real-time tracking system. Lab experiments are critical parts of engineering education, and it is possible to revolutionize engineering labs to be self-paced learning by using AR technology. However, the current hand gesture interactions to communicate with AR devices have shown several limitations. Hence, in this study, we developed a location-based AR system by integrating a real-time tracking sensor and an AR device. This new AR learning system could reduce transition time between learning modules and improve learners' interaction between the modules and an AR device.

Keywords: Augmented reality · Real-time tracking · Engineering education

1 Introduction

Researchers have started to develop effective platforms for educational AR environments [1–6]. Recently, due to the COVID-19 pandemic, every in-person lab class faces a significant challenge to provide high-quality education. AR is a decent technology to resolve the current challenge. Unlike virtual reality, AR does not cover a physical world but mixes virtual objects into the physical world to expand a person's view [7]. Students could advance their learning experiences and spatial sensations in an AR environment. Researchers suggest that learners might have an immersive feeling in the AR environment and tangible connection because hand gestures assist their ongoing cognitive process [8].

However, in the previous AR study [9], students quickly lost their attention due to several usability problems. They would not fully participate in AR exercises and were not actively engaged with the AR system [10]. Another usability issue was that many students felt uncomfortable with the AR system. They needed more time to be familiar with navigating the cursor in the AR system and using hand gestures to select appropriate virtual objects. Therefore, our newly developed AR system aims to improve user interaction between students and the AR environment using a real-time tracking system.

Some researchers suggest that location-based AR applications support collaborative inquiry-based activities [11]. The location-based AR system might enable learners to feel immersive in learning procedures [12]. However, the challenges are the low sensitivity

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to trigger recognition and missing information due to the limitation of global positioning system accuracy. Hence, we used the state-of-art indoor real-time location technology, called Near-Field Electromagnetic Ranging (NFER) system [13], to design a new AR system (Fig. 1). This NFER system can be integrated into the AR system to track users' location and movement in real-time. This system shows a low average range error of 34.0 cm for receivers in positioning [14]. Using the location-based AR system in learning will ensure such activity sequences can be firmly understood and generate significant benefits for learners to improve the learning efficiency.

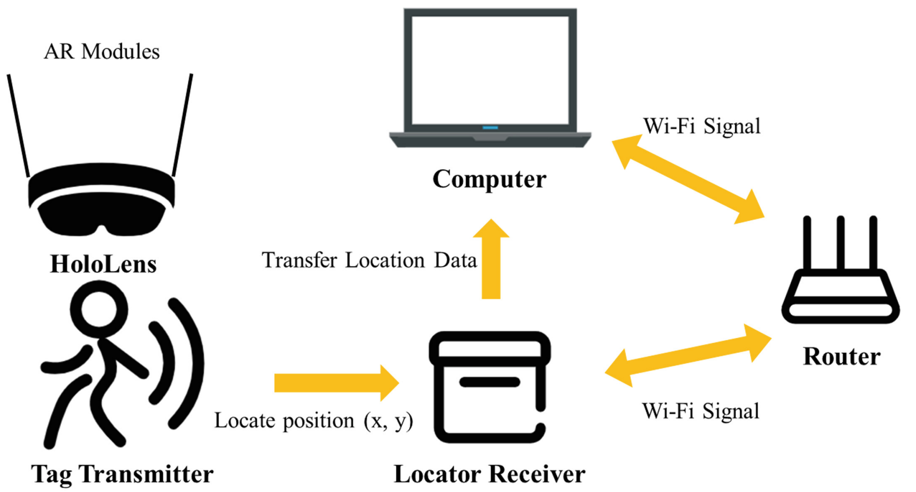

Fig. 1. AR learning system architecture and components

The location-based AR system consists of five components: (1) HoloLens (2) NFER sensors (tags carried by learners), (3) locators (to locate tag position), (4) a laptop with the real-time tracking software, (5) a router (to provide a data link), all of which could cover the whole learning lab. Each tag has a unique frequency. HoloLens is used to exhibit AR modules based on learners' locations.

2 Related Works

Mobile devices, such as smartphones, tablets, and smart glasses, allow users to create, access, process, store, and communicate information without being constrained to a single location [15]. Many AR platforms have used location-based or vision-based triggers to generate media or visual objects [16]. However, HoloLens does not contain any location tracking sensors and cannot access the current location of the users. Besides, GPS does not work accurately indoors. Instead, Bluetooth, Ultra-wideband (UWB), RFID, Wi-Fi, and Zigbee are commonly used as indoor tracking systems [17].

Bluetooth has longer latency, low transmission range, and risk of wireless interference. RFID usually needs manual scans, and it does not provide accurate locational data. UWB needs a complex installation. Wi-Fi is lack scalability. Zigbee has a low transmission range. Table 1 shows the comparisons of indoor tracking technologies.

Table 1. Indoor tracking technology

Tracking technology	Accuracy	Cost	Space dimension	Remarks
Bluetooth	2–3 m	Low	2D	Latency Low transmission range
NFER	<1 m	High	2D/3D	Complex installation
RFID	<3 m	High	2D/3D	Manual scan No true locational data
UWB	15 cm	High	2D/3D	Complex installation
Wi-Fi	<5 m	High	2D	Lack of scalability
ZigBee	1–10 m	Medium	2D	Low transmission range

The existed AR systems commonly use vision-based navigation [18]. Targets or visual makers stimulate AR devices and generate 3D visual content. Users manually search for the targets or markers, and they need to find important information related to the 3D visual content by themselves. However, our location-based AR system is able to retrieve users' x and y coordination, and HoloLens generates appropriate 3D visual content based on the specific locations.

3 System Design

The new AR learning system allows developers to create, develop, and connect to real-time tracking sensors with AR learning content. There are three major design considerations in this new AR learning system.

- **Modularity:** As the new AR system is designed to cater to a wide range of study materials, new features will likely be requested based on the study requirement. Each new component can be developed and tested in isolation before being integrated to create the desired software system.
- **Extensibility:** It is a critical component design for considering future growth. The use of a real-time tracking system allows for fast deployment and easy connectivity to an AR device.
- **Usability:** Users get habits to the new AR learning system, and the platform decreases the user's learning curve, hence making applications that use intuitive design principles. People can easily use the new AR system to create a more diverse engineering education and training content.

The location-based AR learning system is designed with three steps. First, developers need to create the 3D human animations using Autodesk 3Ds max or download them from the Unity asset store. The animation format needs to be fbx file. Second, Mixed Reality Toolkit (MRTK) is an essential tool to accelerate AR development in Unity. Rapid prototyping and extensible framework are provided in the toolkit, such as buttons, spatial awareness, and eye-tracking. Unity includes support for developing the AR content in the HoloLens. Azure is a Microsoft cloud computing service providing computer vision, machine learning, and natural language processing. Third, after development, Visual Studio is used for code editing, deploying apps into the HoloLens. C# programming language is used in the Visual Studio to control the server (Q-track real-time tracking system) and client (HoloLens).

4 System Implementation

This study modified 3D Animation in the assets of the Unity store. For the AR development, we used a predefined HoloLens camera, spatial perception in the Mixed Reality ToolKit. Developers need to know the project setup for the AR environment. Unity supports clips for humanoid animations. After completing the Unity project, it can export a Visual Studio solution for AR deployment in a HoloLens (see Fig. 2). HoloLens can pair to the Visual Studio over Wi-Fi, and the apps can be successfully deployed in the HoloLens. After deployment, users can open applications and use gestures to interact with virtual objects. However, in the new location-based AR system, it is designed to change the apps based on different locations.

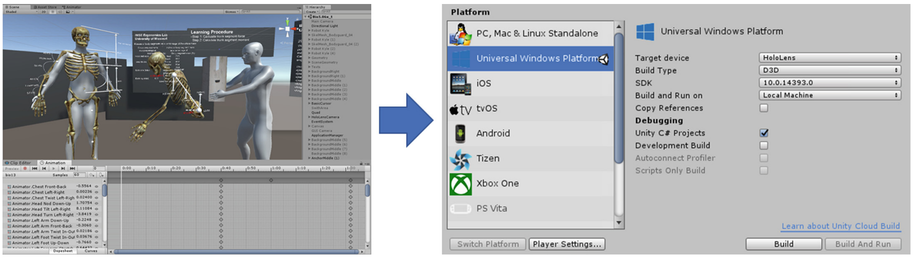

Fig. 2. AR development

The Q-Track NFER system API enables external applications to receive real-time location data from the tracking system. The NFER system is a TCP socket-based protocol allowing the tracking to software (the "server") to send real-time location information to HoloLens (the "client"). The system operates on TCP port number 15752. Table 2 shows the server code, and Table 3 shows the client code.

To connect HoloLens and the NFER system, first, you must make sure that HoloLens and the NFER system are in the same network; Second, run a real-time tracking software, Server TCP and Client TCP; After that, AR learning modules are shown in the AR device. After running the whole system, the real-time tracking software shows tags on the screen (see Fig. 3). The red dot is the reference tag, and the green dot is the user position in the lab. The left side of the figure shows the x and y coordination on the map. If the location matches a specific AR module, the AR module automatically runs in the HoloLens. The right side of the figure shows the apps on the HoloLens.

Table 2. Server

Server Listening at the specific port
Set the **TcpListener** on port 15752 IP Address is "192.168.3.150" Listening for client requests Use **server.AcceptSocket()** to build connection

Table 3. Client

Client Connecting to the server

Create **TcpClient** and connect to Server "192.168.3.150", 15752
Control HoloLens Windows Device Portal in the browser
Read the NFER tag frequency
Set up the Zone area and x & y coordination
If (x, y) lasts than two seconds, **then**
Show the AR module in the (x, y)
Else
Keep the same AR module

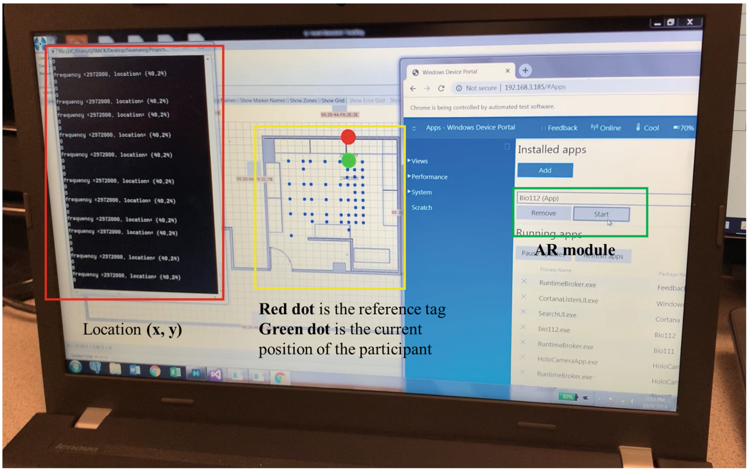

Fig. 3. Real-time tracking software and AR modules

5 Application

In this study, we used a biomechanical lecture as a testing AR learning module. It is one of the ergonomic class materials. Biomechanics shows 3D models of the internal and external force and moment. The location-based AR system can enhance students to recognize spatial visualization and will be beneficial to improve spatial awareness. Figure 4 shows the view in the experiment.

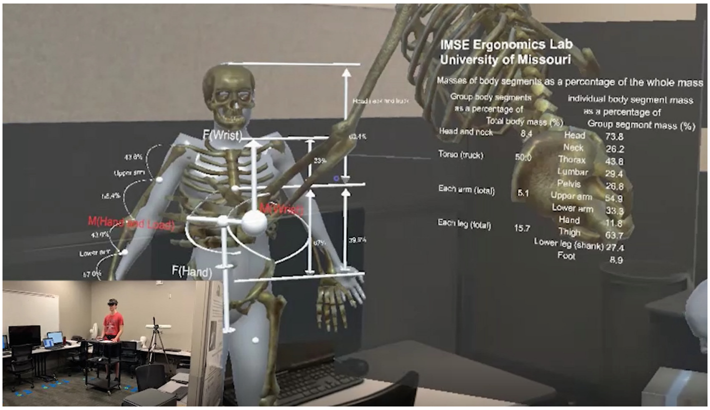

Fig. 4. AR learning experiment using Biomechanical Lecture

Figure 5 shows the experiment setting on the lab floor map with 14 scenes. Each position matches a specific scene in the AR learning environment. Students could move back and forth to learn the next or previous module by walking to that spot. According to the experiment results, real-time location interaction helped students reduce training time and frustration.

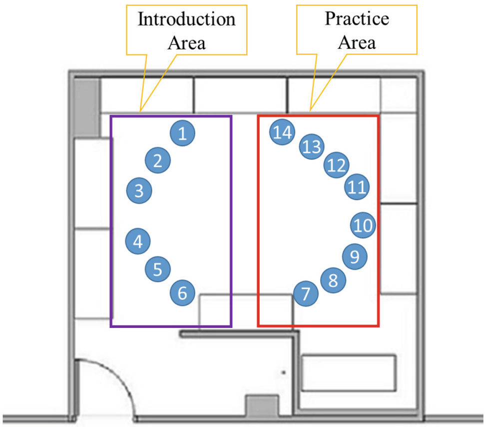

Fig. 5. Lab Floor map with fourteen AR scene spots

6 Conclusion

In conclusion, the advanced AR system by integrating a real-time tracking sensor reduced the transition time between learning modules and improved learners' interaction experience. AR technology is beneficial to improve spatial recognition to enhance students' learning performance. Based on the current study, the location-based AR system will be useful in medical surgery collaboration training, advanced industrial manufacturing systems integrating robot manipulation, and humans to execute tasks in a stereoscopic environment. This AR system could locate user positions in the working areas and shows specific learning knowledge to them. It will help users to operate machines effortlessly without geographical limitations and decrease potential industry accidents. Overall, the new location-based AR system will improve the learning experience and human-computer interaction.

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Practical Evaluation of Impression and Aesthetics for Public Displays: A Case Study in Evaluation of Platform Display Design

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Abstract. In the present paper, we apply psychological approach for impression, perception and aesthetics evaluations of public display design considering its competing business context. In designing of approach, we developed questionnaires and two versions of data collection methods with application guidelines. The approach was developed for practitioners, thus it included deep consideration about managerial limitations (e.g., time, cost, skill/knowledge needed for implementation). The proposed approach, which was simple and could be carried out easily, was applied to our case study where three platform displays' evaluations were carried out. Results of evaluations as well as implications are discussed.

Keywords: Platform display business · Aesthetics · Impressions · Visibility

1 Introduction

In the context of manufacturing business including materials of public display businesses, it is recognized that differentiating the product from those sold by other competing companies is a key success factor (e.g., [1]). Focusing on the context of public displays business (e.g., manufacturing companies producing platform display, billboard and so on), one of the minimum requirements to achieve this is to assure that the specific display's visibility is satisfactory with potential customers' need within given limitations (e.g., cost). In today's strict competing business environment, however, some additional values rather than fundamental values (i.e., functional benefit) are needed to stimulate the potential customers' purchase intentions. In present common understanding of the trend in assessment of designs, it is said that acquiring human responses to designs indicate a move towards assessing designs from an impression point of view rather than a task point of view such as visibility [2]. Considering this, we can expect that one promising value is an impression/psychological feeling generated by a specific material/display. By changing a material's diffuse reflection of light, for example, a specified display made by the material may be able to make people feel some specific impressions like warmness, cool and so on. We can expect that this kind of impression/feeling generated can be an attractive new characteristic of a public display [3].

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As a background of the present study, one of Japan's manufacturing companies with which we collaborated in this research began to release a new display where a new material was used. This material was developed for outer illumination type displays. The material has an unique characteristic in its diffuse reflection of light. This unique characteristic contributes to effective reflection of lights, thus is expected to contribute to reduction of electricity consumption. The main target customers are railway companies (i.e., platform displays) since they are expected to need high visibility displays with low electricity. In addition to the railway companies, the company is seeking for potential customers such as advertising companies. The company, a public display business in strict competing environment, needs to know unique/special benefits of the display made from the new material. Especially it would like to know the material's impression-related characteristics as an additional value for potential customers. The company, therefore, is exactly in the business situation which is explained in the preceding paragraph. In the present paper, we aim at developing a practical approach for evaluation of impression and aesthetics-related aspects of public displays. Underlying idea of the proposed approach is to enable us to analyze materials' impressions and aesthetics acceptable in business context, meaning that the approach should be scientifically rigorous yet also very simple and time-saving, and therefore acceptable for practitioners.

In most of academic research relating impression evaluations, semantic differential (SD) method based on pairs of adjective words (e.g., Osgood [4]) has been a major methodology. Using the SD method, a number of researchers have performed public displays' impressions evaluations research. In a traditional work by Oullette [5], for example, effects of luminance and opacity of the sign of legend and background were examined. Schoolery and Reagan [6] analyzed effects of lighting on visibility of exit signs. Though quite many research where influences of key design factors of public display (e.g., size, configurations luminance etc.) to visibility/impression were examined, it has been said that as a common recognition the considerable disagreement on requirements for such key design factors for public display design have existed because the human mechanism of generation of perceived visibility is very complex (e.g., [7]). This indicates that whenever we need to know visibility/impression of a specified display (e.g., a specific product), we have to evaluate it somehow because accurate predictions of visibility perceived are not possible.

Considering the above-mentioned background, the objective of this case study is to develop a simple analysis procedure in which responses to questionnaire of aesthetics, impressions and preferences, and apply it in a business context. In the procedure developed, we design two variations of data collection methods and guidelines how to select an appropriate method depending on displays' easiness of impression perceptions.

2 Platform Displays Focused

In our case study, we used the following three platform displays: D1, D2 and D3. The D1 and D2 are outer illuminated display, and D3 is an internally illuminated display. The characteristics of the displays are summarized in Table 1. Outer illuminated displays are shown without any light in daytime, and are shown with a few outer lights in night time. Internally illuminated displays are shown with sufficient numbers of LED lights in all day. Caused by the illumination type (outer/internally), the brightness perceived of D1 and D2, in general, are much lower compared to D3. But the running cost as well as initial cost of outer illuminated displays are much lower than those of internal illuminated displays.

D1 is made by the collaborating company's new material. The current station written in Kanji characters is shown in a large font in the center of the display with its Hiragana characters and Romanized version. They are written by black characters on white background. The preceding and succeeding stations are shown in relatively a small font in the left and right of the display, respectively. The D1's material has a special feature in diffuse reflection of light. The D2's size and look are exactly the same as the D1's. D2's material, however, is a standard one not having any special feature regarding light reflection. The D2 is the competing product of D1 for the company. D3 is an internal illuminated display shown in the premises of train stations. This shows lines, track numbers, exits with signs to guide passengers.

Table 1. Characteristics of displays.

	D1	D2	D3
Illumination type	Outer illuminated	Outer illuminated	Internally illuminated (LED)
Size	450 mm × 1280 mm	450 mm × 1280 mm	450 mm × 1400 mm
Characteristics of light reflection	Semi-directional diffuse reflection of light	Ordinal	–
Content	The current station as well as its preceding and succeeding stations	The same as D1	Lines, track numbers, exits (Guide in stations)
Initial cost	Medium	Low	Expensive
Running cost	Very low	Low	Expensive

3 Analysis Procedure Developed

3.1 Perceived Visual Aesthetics Question Items

Though the present research is focusing on platform displays, the materials of the displays have to be used not only for platform display, but also for public displays such as advertising boards. In advertising board design, for example, it seems that visual impressions given to consumers, which is strongly affected by characteristics of display materials, is one of the key success factors. In addition to visibility, therefore, another evaluation dimension relating to impressions is employed. We classified the question items into the following four categories: Overall aesthetics, perceptions/impressions, overall preference and overall visibility.

Overall Aesthetics. The degree in which overall aesthetics perceived is measured by the question "How aesthetic is the display? [8]."

Perception/Impression. Considering the needs elicited from the materials business context, we selected six adjectives from typical SD scales [9] to fit the platform display evaluations. The adjectives are relating to familiarity, warmness, calmness, luxury, well-organized and cleanness.

Overall Preference. The following two questions are adopted: "How much do you like the display?" and "How cool is the display?".

Overall Visibility. Considering the environment where the display is exposed, we choose the following question: "How salient is the display?".

3.2 Two Versions of Data Collection

In the previous relating research where perceptual quality of screen is measured, both methods of single stimulus and double stimulus (pair-wise comparison) are recommended [10, 11]. In the single stimulus method, subjective ratings/scores are assigned to each stimulus (i.e., display). In the double stimulus method, on the other hand, subjective ratings/scores are given between two stimulus. Accurate and reliable measurement results are expected by applying double stimulus method when the difference of visual quality perceived is small [9]. However, it is also said that a double stimulus method is relatively time-consuming compared to single stimulus method [12]. Considering this, we prepare two types of data collection methods: single and double stimulus methods. The method selection should be conducted based on the perceptual difference of visual quality of displays. Namely, if the difference of visual quality is small and therefore it is quite difficult to perform single stimulus method, double stimulus method is recommended.

4 Case Study

4.1 Objectives

The overall objective of the case study is to check feasibility of the analysis procedure by identifying characteristics of the D1 and two displays (D2 and D3). Our case study is composed of two experimental sessions (sessions 1–2). In session 1, an internally illuminated display D3 is examined by applying single stimulus method. Since the single stimulus method is applied to D3, the influences of key factors to impressions are also examined. In session 2, we examine D1 and D2 (D1's competing product) by applying the double stimulus method. This distinction of applied methods depending on the displays is because the perceptual difference of visual quality between D1 and D2 are very small.

4.2 Participant

Twenty-three healthy individuals (3 women and 20 men) participated in our feasibility study as paid volunteers. They were university students with a median age of 21 years old (ranged from 18–24). They had normal or corrected-to-normal vision. All participants signed an informed consent form approved by the ethics committee of Tokyo Institute of Technology (A18087).

4.3 Overview of Sessions

Session 1. A display was set at a distance of 12.4 m from a participant, and the height of the display was 2.5 m. As key factors affecting impressions, we picked up the following two factors: luminance and color temperature. The luminance had three conditions of 400 cd/m^2, 650 cd/m^2 and 900 cd/m^2, and the color temperature had two conditions of 5,000 K and 5,800 K. Thus this session used a 3 $\times$ 2 within subjects design. The participants were treated as repetitions. The experimental task was to read through D3 silently, and to give subjective ratings to questionnaire items. Overall aesthetics and overall visibility scores were obtained. A participant gave rating scores on a five-point Licart scale between 1 and 5 (see Table 2). Upon arrival at our experimental site, each participant was briefed on the overall objective of the experiment, tasks to be conducted, and questionnaire. A participant was asked to be seated in a chair. The experimental tasks composed of 6 trials (3 luminance levels x 2 color temperature levels) were then started. In each trial, the participant provided his/her responses to the questionnaire. The order of the trials was randomized.

Session 2. A pair of two displays (D1 and D2) was set at a distance of 2.85 m from a participant, and the height of the display was 2.5 m. As a key factor affecting impressions, we picked up illuminance here. The illuminance had three conditions of 16 lx, 100 lx and 650 lx. The participants were treated as repetitions. Task. The experimental task was to read through D1 and D2 silently, and give subjective ratings to questionnaire items. Metrics. All category scores were obtained by applying double stimulus method. A participant gave rating scores on a five-point Licart scale between -2 and $+2$ (see Table 2). A "+2" response represents that D1 is very positive/superior compared to D2, a "0" response represents that D1 is equals to D2, and a "-2" response represents that D1 is very negative/inferior compared to D2. Each participant was briefed on the objective of the session, tasks to be conducted, and questionnaire. A participant was asked to be seated in a chair. The experimental tasks composed of 3 trials were started. In each trial, the participant provided his/her responses to the questionnaire. The order of the trials was randomized.

5 Result

5.1 Session 1

Table 2 summarizes the mean values of scores (overall aesthetics and visibility) and ANOVA results. As shown in this table, 2-way ANOVA revealed significant differences with the factors of luminance and color temperature. There existed a significant positive effect of luminance to overall aesthetics perceived. Considering the fact that D3 could obtain slightly positive score (3.63) in 650 lx or higher conditions, we may be able to say that the 400 lx, at which the mean score was 3.13, was not sufficient to convey subjective aesthetics. As for the factor of color temperature, a significant positive effect was found. From the mean scores, it may be conjectured that some thresh old by which subjective aesthetics could be felt was close to 5800K since the mean score at 5800K (3.63) was higher than 3.50.

In overall aesthetics scores, we could not identify any significant interaction effect. In overall visibility scores, very clear effect of luminance was found. It seemed that sufficient visibility could be obtained at 650 lx or higher conditions. We could not find any significant effect of color temperature nor interaction effect on visibility from our data.

Table 2. Mean values and ANOVA results.

Metric	Luminance				Color temperature			Interaction
	400	650	900	F-value $F(2,90)$	5,000	5,800	F-value $F(1,90)$	F-value $F(2,90)$
Overall aesthetics score	**3.13**	**3.63**	**3.74**	8.99**	**3.37**	**3.63**	4.47*	0.54
Overall visibility score	**3.05**	**4.03**	**4.58**	45.96**	**3.84**	**3.93**	0.44	2.15

**: $p < 0.01$, *: $p < 0.05$

5.2 Session 2

The raw rating data for each illuminance condition were analyzed by a paired t-test to find if there existed significant differences between the two displays (D1 and D2). Table 3 shows the mean values of scores for each illumination condition and t-test results. For example, we can interpret that in overall aesthetics score, D1's subjective aesthetics was significantly better than D2's in 100 lx and 350 lx conditions.

As shown in this table, D1 could give significantly positive aesthetics compared to D2 in illumination conditions of 100 lx and 350 lx. The same tendency, where D1 showed relatively better performance than D2, could be found in the following perception/impression metrics: familiarity score and warmness score. Significantly negative impressions, on the other hand, were identified in the followings: well organized score and cleanness score. However, such negative effect was found only in very dark illumination condition (i.e., 16 lx). As for overall preference metrics, we could obtain a tricky result. D1 could obtain relatively better scores in 100 lx and 350 lx conditions, while it obtained inferior scores in coolness scores in all illumination conditions. In overall visibility, D1 could obtain relatively better scores in 100 lx and 350 lx conditions.

Table 3. Mean values and *t*-test results.

Evaluation category	Metric	Illumination(lx)		
		16	100	350
Overall aesthetics	Overall aesthetics score	**0.00**	**0.52**	**0.52**
	$t_0(22)$	0.00	2.79^{*}	2.31^{*}
Perception/Impression	1. familiar	**0.30**	**0.83**	**1.13**
	$t_0(22)$	1.32	3.56^{**}	5.60^{**}
	2. luxury	**−0.35**	**−0.04**	**−0.35**
	$t_0(22)$	−1.62	−0.18	−1.70
	3. warm	**1.09**	**1.36**	**1.26**
	$t_0(22)$	10.13^{**}	8.80^{**}	7.47^{**}
	4. calmness	**−0.26**	**−0.30**	**−0.26**
	$t_0(22)$	−1.10	−1.67	−1.19
	5. well-organized	**−0.43**	**0.04**	**−0.35**
	$t_0(22)$	-2.33^{**}	0.27	−0.25
	6. cleanness	**−0.65**	**−0.30**	**−0.26**
	$t_0(22)$	-3.54^{**}	−1.50	−1.37
Overall preference	1. liking	**0.00**	**0.52**	**0.48**
	$t_0(22)$	0.00	$1.82^{\dagger}$	$1.91^{\dagger}$
	2. coolness	**−0.74**	**−0.48**	**−0.35**
	$t_0(22)$	-5.15^{**}	-2.31^{*}	$-1.78^{\dagger}$
Overall visibility	overall visibility score	**0.17**	**0.83**	**0.65**
	$t_0(22)$	0.75	4.03^{**}	3.04^{**}

**: $p < 0.01$, *: $p < 0.05$, †: $p < 0.10$

6 Discussion

In principle, it can be assumed that both of aesthetics and preference are affected by impression considering a causal relationship mechanism. Thus, we discuss the influence of impression to perceived aesthetics and preference. In addition, we discuss whether the perceived visibility is a key factor affecting aesthetics and preference.

First, we calculated a correlations coefficient between overall aesthetics score and overall visibility score obtained in session 1. From this analysis, we can obtain insights regarding internally illuminated displays. The correlations coefficient was 0.375 ($t_0(112) = 3.97, p < 0.01$). This may indicate that though the visibility perceived is positively correlated with the aesthetics, the visibility is not a dominant factor determining aesthetics because the coefficient is not so high.

From session 2, we can obtain insights of outer illuminated displays. The impression scores except the calmness score positively correlated with the aesthetics score, while the calmness score negatively correlated with the aesthetics score. Obviously, we could indicate that the feelings of familiarity seemed to be a key impression determining the perceived aesthetics. In preference scores, interestingly, we could find different trends in liking score and coolness score. As for the liking score, a very similar trend with the overall aesthetics score could be found. The impression scores except the calmness score positively correlated with the aesthetics score, while the calmness did not show any significant correlation with the aesthetics score. It seemed that the feelings of familiarity was a key impression affecting the perceived aesthetics. In coolness score, on the other hand, no significant correlation was found. Furthermore, we could not find any obvious key impression related to the perceived coolness since all of the correlation's coefficients showed relatively low values compared to liking scores. As expected, we could identify relatively strong positive correlations between visibility and aesthetics/preference (except coolness score). From this result, it was ascertained that the perceived visibility was necessary to convey the aesthetics/preference.

7 Conclusion

This paper reported an practical analysis procedure where aesthetics, perception/impression and preference-related aspects could be revealed. Considering the business context, we aimed at simple procedure that can be accepted in the businesses environment. The procedure was composed of four evaluation categories having just 10 question items. A feasibility study in which twenty-three participants participated was carried out to evaluate a specific new product as well as competing products. By applying the procedure, we could clearly characterize D1 as well as its competing displays (D2 and D3).

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Location of the Shift Technical Advisor Role in Nuclear Power Plant Scenarios - Impact on Performance

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Abstract. This paper presents a simulator study investigating two research questions: Will physical location of a shift technical advisor (STA) affect 1) nuclear power plant crew performance? 2) the fulfilment of expected STA duties? Two of six planned crews participated before the travel restrictions from Covid-19. Each crew run through six complex scenarios lasting for 40–60 min. The location of the STA varied as follows: 1) seated right next to the shift supervisor at the same workstation 2) at a separate workstation in the same room as the crew, 3) at a separate workstation in a separate room. Process expert ratings and operator self-ratings indicated a better crew performance when STA was located in condition 1). Furthermore, process expert ratings indicated that the STA performed his expected duties better when located in condition 3), while the operators preferred the STA to be located in condition 1).

Keywords: Simulator study · Nuclear power plant operators · Shift technical advisor · Location of crew members · Crew performance

1 Introduction

Through the international OECD/NEA Halden Reactor Project (HRP), several studies have been performed in the nuclear power plant (NPP) simulators in the Halden Man Machine Laboratory (HAMMLAB). In some of these studies, we have made observations, not directly related to the research question of the study at hand. An example of such observations is a negative performance effect when operators have been located physically close to each other [1, 2]. We wanted to perform a dedicated simulator study in order to investigate these observations in more detail and decided to focus on the shift technical advisor (STA) role. The STA is an important role within the control room crew, as his/her advice to the crew may have direct implications for the safety of the plant. In addition, several plants are currently discussing the STA role, and whether the STA could support several units from a central position outside the main control room.

1.1 The NPP Control Room Team

It has been claimed that when teamwork is performed well, this is one of the best ways to reduce errors and prevent consequences of potential errors and incidents (e.g., [3, 4]).

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Normally, a NPP team consist of a shift supervisor and at least two reactor operators. The shift technical advisor is an additional team member intended to provide additional engineering competence and support [5]. The NPP operators go through structured training before they become licensed operators, and regular refresher training in the simulator is mandatory in order to maintain their license.

1.2 The STA Role

The STA role was implemented as a requirement by the Nuclear Regulatory Commission (NRC) after the TMI-2 (Three Mile Island) accident [6, 7]. Examinations after the accident suggested that technical expertise prior to, during and immediately after an accident should be strengthened. The required qualifications of the STA were "engineering expertise, training in the details of design, function, arrangement and operation of plant systems, and special training in plant dynamic response." ([6] p. I-1). When it comes to the role and responsibilities of the STA, NRC states that "when assigned as shift technical advisor, these personnel are to have no duties or responsibilities for manipulation of controls or command of operations." ([8], p. A-50). Furthermore, the STA reports to the shift supervisor during off-normal plant conditions in an advisory capacity and shall not assume command or control functions.

The organisation of the STA role has been discussed. An STA that is integrated into the control room crew is, according to NRC, more up to date on the daily operation and thus better able to support the crew when needed [9–11]. In case of an event, the STA will thus have been involved in the events leading up to the incident and have a better situation understanding than if the STA is called to the scene from outside. On the other hand, an STA that is more independent and not so integrated into the team is less likely to be affected by biases and groupthink occurrences that may be present in the crew [12, 13].

1.3 Human Redundancy and Cognitive Diversity

Researchers have pointed out that by introducing an extra role in the shift team (as has been done with the STA), there is a potential improved opportunity for the crew to detect and correct errors, which again may provide increased redundancy in the crew.

A framework that describes the mechanisms of human redundancy in relation to error recovery was proposed by Clarke [12]. Clarke focuses on the "recovery of an error made by an individual through the intervention of another" ([12], p. 657), although human redundancy also could be detection and recovery of faults caused by system or equipment failures. Westerman et al. [14] point out the distinction between redundancy and diversity. Redundancy is used as a way to achieve fault tolerance by using more than one component of the same type. If one of the components fails, the other can take over the function. However, identical redundant components can be prone to common-mode errors. By using diverse technical components, design errors will be less likely to impact several redundant components. A similar point can be made for human redundancy: "Failures in the performance capacity or strategies employed by one individual may well be shared by others, and, as a result, all individuals may make common errors." [14], p. 142.

The STA is supposed to provide support to the crew in normal and abnormal situations. However, placement of the STA close to the shift supervisor may not be optimal for crew performance [1, 2]. According to Clarke [12] and Kirwan [13], there will be less dependence between the redundant role (here: STA) and the team if the redundant role is not fully integrated in the operating team. It may thus be possible that the placement of roles within the control room may influence the degree to which an independent checker role (such as STA) is likely to be effective.

2 Purpose of the Study

The aim of the empirical study is to address whether physical location of the STA in a nuclear control room affects crew performance and furthermore whether the location of the STA affects the fulfilment of the expected duties of this role as an independent advisor. The location of the STA role varied in three different ways:

1. STA located at the same desk as the shift supervisor
2. STA located at a separate desk with some space from the other team members and access to monitoring the process from separate process displays
3. STA located in a separate room, with access to monitoring the process from separate process displays and a possibility to see and hear and communicate with the other operators

The following research questions (RQ) were outlined:

RQ 1: Will physical location of the STA affect crew performance? Based on observations and previous findings, we anticipate that the crew will perform better when STA is located in position 2 and position 3 than in position 1.
RQ2: Will physical location of the STA affect fulfilment of expected STA duties? Based on observations and previous findings, we anticipate that the STA will perform the expected STA duties better when located in position 3 than in position 1 and 2.

3 Study Description

This study took place at the Generic Pressuriser Water Reactor (GPWR) simulator in HAMMLAB, a computerised full-scope model of a 3-loop Westinghouse NPP.

Six crews of licensed operators from three different Westinghouse plants were invited to participate. Only two crews participated before Covid-19 put a stop to further data collection. Both crews consisted of four operators, taking on the following roles: one shift supervisor (SS), one reactor operator for the reactor side (RO), one reactor operator for the turbine side (TO), and a shift technical advisor (STA). All participants took the same role in the simulator as they currently held, or had quite recently held, at their home plant. All operators participating in the study were experienced licensed operators, and the average age of the operators were 39 years.

Six scenarios were designed for this study. All scenarios included situations requiring STA support. The scenarios lasted for 40–60 min. The order of the scenarios and the experimental conditions were counterbalanced. Prior to the scenario runs, the operators received training in the simulator interface. Before each scenario, a process expert (PE) provided the crew with handover information. For all scenarios, the operators had access to necessary procedures. Each scenario was followed by questionnaires. After the last scenario, a semi-structured group interview was conducted. The data collection was rounded off by a short debriefing session, where the operators were given the opportunity to ask questions about the study.

During the scenarios data were collected in the form of audio and video recordings, simulator logs and observations. Operator self-ratings, interviews and process expert evaluations were collected after the scenarios. The operator self-ratings included questionnaires on task complexity [15], workload [16], self-rated crew performance, situation understanding and perception of STA contribution. The process expert evaluated crew performance using the Supervisory Control and Resilience Evaluation (SCORE) measure (se e.g. [17]), and on fulfilment of STA's assigned duties to *Maintain oversight* and *Make recommendation*s as described in [8].

4 Results and Discussion

4.1 Will Physical Location of the STA Affect Crew Performance?

Crew performance as rated by the process expert using the SCORE inventory [17] revealed a performance effect ($p < .10$) of the different locations of the STA, in favour of condition 1, as displayed in Fig. 1.

Dependent t-test analyses of the operators' self-ratings revealed differences between some of the conditions. Results with a significance level of $p < .10$ are reported in Table 1. We can see that operators rated their own situation awareness and performance higher in condition 1 than in condition 2, and also higher in condition 1 than in condition 3. Workload was rated higher in condition 1 than in condition 3. There were no significant differences in operator self-ratings when comparing condition 2 with condition 3.

By being more informed and hearing the discussions between the STA and SS in conditions 1 and 2, the operators felt that they had more control, and thus better performance and situation awareness, than when STA was outside the control room, in condition 3. When STA was inside the control room, they could follow the conversation between the STA and SS, and in this way be in the loop of what was going on. Furthermore, it is understandable that the operators felt higher workload when STA was outside the control room, as STA would not, in the same way as when he was inside the control room, be able to relieve the crew in certain tasks which it seems he was doing in condition 1 and 2.

The process expert and the operator rating of crew performance when the STA was located in the three different conditions seem to converge and point towards a better crew performance in condition 1. Based on our observations in previous studies, were we observed that crew performance deteriorated when crew members were located close to each other [1, 2], we anticipated that distance between the crew members would affect performance, and that crews thus would perform better when STA was located in condition 2 or 3. This anticipation was not supported in our data. Contrary to our expectations, crew performance seems to be better when STA is located in condition 1, next to the shift supervisor.

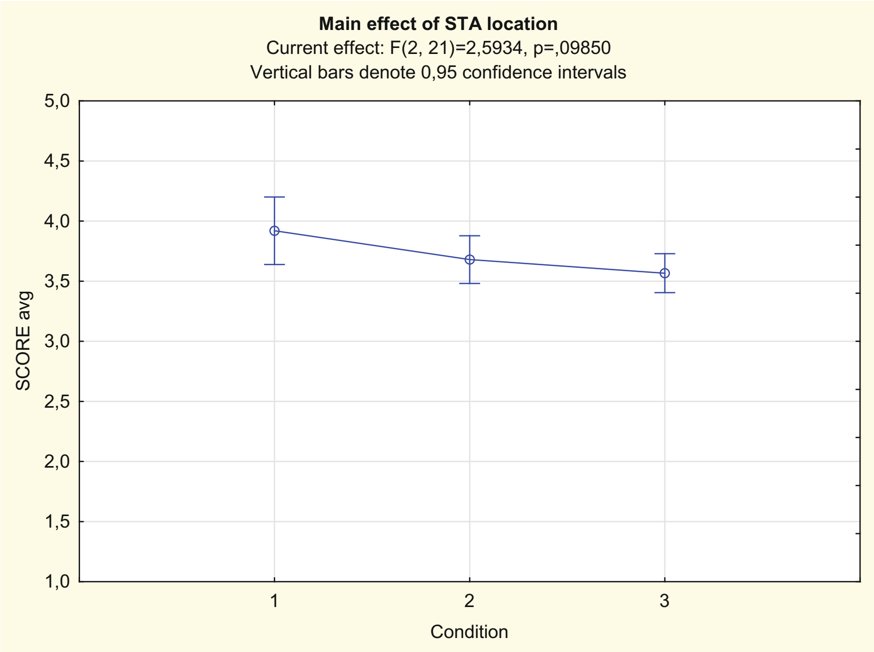

Fig. 1. Process expert rated crew performance

Table 1. Dependent t-test of operator self-ratings in the three conditions, $p < .10$

Operator self-rating	Condition 1 and 2	Condition 1 and 3	Condition 2 and 3
Situation awareness	$t\ (15) = 3.09$	$t\ (15) = 2.18$	–
Performance	$t\ (15) = 2.43$	$t\ (15) = 3.16$	–
Workload	–	$t\ (15) = -2.74$	–
Task complexity	–	–	–

There are several aspects that can have influenced the results in our study. When the STA was located next to the shift supervisor, he was often used as an additional crew member, which may have improved crew performance at a general level. Also, when the STA was located in a separate room, he may have provided the crew with advice that was not followed by the crew, thus not leading to the performance improvement that it might have in the co-located conditions. These considerations are partly speculations, but we cannot ignore that such factors may have influenced the results. Even though we should be careful with firm conclusions in a study with few participants, it seems like research question 1, Will physical location of the STA affect crew performance? is supported in our data. There is a difference in crew performance in the three different conditions, however, not in the way we expected.

4.2 Will Physical Location of the STA Affect Fulfilment of Expected STA Duties?

The second research question concerned the STA role as an independent advisor. When looking at the operator questionnaire regarding location of STA, condition 1 was the most preferred for nearly all aspects evaluated by the operators (workload, cooperation, mutual trust, team performance). Condition 2 was rated highest with regard to STA contribution, and the operators found condition 1 and 2 equal with regard to their situation understanding.

The process expert analysed the STA role as an independent advisor based on the degree to which the duties as STA were fulfilled, as described in [8]: *Maintain oversight* and *Make recommendations*. Two scenarios from each condition (three scenarios from each crew) were selected for this analysis. In the two scenarios from condition 1 the process expert found that STA was successful in *maintaining oversight* in 4 of 10 opportunities and *providing recommendations* in 7 of 10 opportunities. In condition 2, the STA was successful in maintaining the oversight role 3 times in 12 opportunities and providing recommendations 5 times in 12 opportunities. The two scenarios in condition 3 saw 10 opportunities to maintain oversight and provided recommendations and the STA was successful in all 10 instances. This is illustrated in Fig. 2.

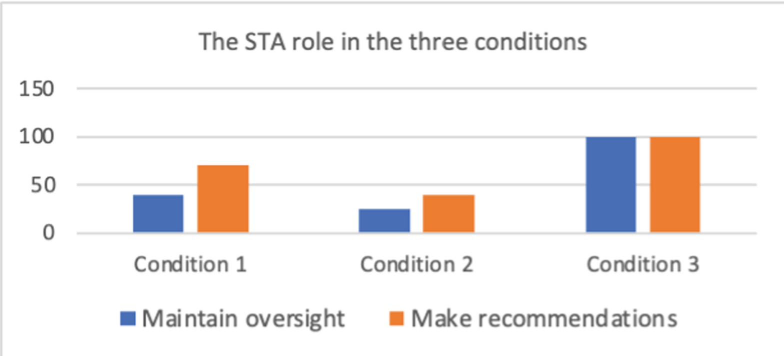

Fig. 2. Process expert analysis of STA assigned duties in the three different conditions. The y-axis represents percentage of successful opportunities

Analyses of communication between the STA and the shift supervisor supports the process expert finding: The STA gives more independent contribution when located in condition 3. The STA and SS communicated most in condition 1, but the proportion of meaningful statements that contributed to the scenario completion was higher in condition 3.

There seem to be a discrepancy between the way the operators experienced the STA role and how the process expert evaluated the STA role.

The crew may appreciate that the STA, when located in condition 1 and 2, contributes as an additional resource that can offload some of the work in situations of high workload. In a situation that is unfamiliar it is natural for the crew to want to use the experience of an STA in hopes of gaining a better understanding of what is happening to the plant and how to respond to the situation.

However, an STA who is working as an additional team member may have difficulty maintaining his independence when he is part of the crew. Therefore, it is important for the STA to be aware of their role and stay focused on not becoming just another crew member and instead maintain the oversight and advisor role that is clearly defined in the conduct of operations guideline.

With regard to research question 2 - Will physical location of the STA affect fulfilment of expected STA duties? - there is a discrepancy in the results between the operator ratings on the one side and the process expert evaluations and the communication analyses on the other side. Although the operators prefer that STA is located in condition 1 or 2, the process expert ratings suggest that the STA role is best exercised in condition 3, which point in the direction we expected, meaning a partial support in the dataset for the second research question.

5 Conclusion

Based on the data collected and the analyses performed in this study, it may seem like the crew has best performance when the STA is located close to the rest of the crew, but that the STA perform his intended duties better when located in a separate room. The operators preferred to have the STA in the same room, but in that condition, we observed that the STA was not used according to the requirements for the role. Also, to be able to understand whether the STA could be responsible for giving advice and recommendations to several units at the same time, we need to perform additional studies where the focus is to examine STA's situation awareness and workload in that condition. In addition, aspects such as mutual trust between the crew and the STA when the STA is located outside the main control room need to be further investigated. We are cautious to provide recommendations regarding STA location, particularly due to the small number of participants. What is needed before recommendations can be made are to find practical, safe and secure solutions to support the information available for the STA if located outside the main control room, or to find ways to better support the STA in performing according to the defined role when located together with the rest of the crew.

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Psycho-Educational Intervention Program to Eradicate Sexual Harassment for University Students

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Abstract. The present research study allowed fulfilling the objective of proposing a psychoeducational intervention program, according to the conception of violence, to eradicate sexual harassment in students of the Faculty of Engineering of the Universidad Nacional de Frontera in Sullana, Peru. The research is non-experimental and has a descriptive-correlational-propositional design. The sample consisted of 182 students, obtained by non-probabilistic convenience sampling. The survey technique was applied through two instruments: Inventory of conception of violence and the scale of perception against sexual harassment. The results indicate that there is a positive correlation, with strong strength and significance level ($p < .05$), between the variable conception of violence of the program proposal and the perception of sexual harassment. In addition, approval was found with significant percentages in the following beliefs: "Sexual harassment occurs because one allows it", "Most reports of sexual harassment are false", and others.

Keywords: Conception of violence · Sexual harassment · Psychoeducational intervention program

1 Introduction

The current world characterized by constant competitiveness, has led us to develop a culture of violence, where everything is intended to be solved with vehemence and momentum loaded with aggressiveness. Comparable only to the Darwinian law of the prevalence of the strongest, where sexual and sexist behaviors are naturalized, where the people involved end up minimizing or justifying these attitudes, so they decide not to denounce, and there is no sanction for these acts.

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The Peruvian University Law [1], establishes that higher education centers must respect dignity and express their support for the prohibition of violence, intolerance and discrimination, ratifying this with the Law of Prevention and Punishment of Sexual Harassment [2]; where it establishes that the administrative processes of sanctioning professors for these acts in general, being immersed the university defender and/or directorate of university welfare to establish procedures, prevention activities, development of regulations and working tables for these cases.

The general objective of this research was to propose a psychoeducational intervention program, to eradicate sexual harassment in Sullana university students and the specific objectives: First, to determine the level of perception of the conception of violence, in the dimensions: Cognitive reflection, emotional consciousness and behavioral assessment; second, to determine the level of perception of sexual harassment in the dimensions generic qualification, denial of rights and gender image; third, to identify the beliefs that justify sexual harassment; fourth, to determine the relationship between the level of perception of the conception of violence and the level of perception of sexual harassment, and fifth to propose a psychoeducational intervention program to eradicate sexual harassment in Sullana university students.

2 Methodology

2.1 Hypothesis

The proposal of the psychoeducational intervention program, according to the conception of violence, would eradicate sexual harassment in Sullana university students.

2.2 Type of Study

The present study has been developed from the quantitative approach [3], it is of Applied type [4]. In terms of its depth, it is non-experimental [5]. With descriptive design whose purpose has allowed characterizing the study phenomenon through the survey and the use of two questionnaires [6], it is also correlational, since it sought to locate the existing relationship between the two variables that were investigated [7] and finally it was propositional in that it offers a psychoeducational intervention program, to eradicate the beliefs in the face of sexual harassment [8].

2.3 Variables

Independent Variable: Conception of Violence. Referred to actions that violate human rights, product of a vicious circle that is established in the triangle of violence, where cultural violence (thoughts and attitudes) justify direct violence (physical, verbal or nonverbal actions) and structural violence (power, inequality) as stipulated by Galtung (2016). This variable was measured with its three dimensions:

Cognitive Reflection: Referring to the rational thoughts of young people in relation to violent situations.

Emotional Consciousness: Where it recognizes the emotions generated by violent situations.
Behavioral Appraisal: Where acts that are evidenced as violent situations are recognized.

Dependent Variable: Perception of Sexual Harassment. Meaning given to repeated physical or verbal conduct of a sexual nature that is unwanted or rejected, that affects the dignity and fundamental rights of the aggrieved person, that occurs in the context of authority or dependency relationships, but also regardless of hierarchies (Congress, 2003). This variable has been measured with its three dimensions:

Generic Qualification: Valuation that faces acts of sexual harassment.
Denial of Rights: Recognition of the human rights that are violated in situations of sexual harassment.
Gender Image: Valuation of gender roles based on equality.

2.4 Data Collection Techniques and Instruments

Document analysis and the survey were used as techniques, the latter working with two questionnaires, which followed the following procedure: First, general information was provided on the definition of sexual harassment and gender violence, then informed consent was given and finally the scale of Perception of sexual harassment and the scale of conception of violence were applied.

2.5 Data Analysis

A Microsoft Excel database was used, which was then transferred to SPSS version 24.0, using descriptive and inferential statistics.

3 Results

3.1 Specific Objective 1.

To determine the perception of the conception of violence in the following dimensions: cognitive reflection, emotional consciousness and behavioral assessment in Sullana university students, as shown in Table 1.

Table 1. Level of perception of the conception of violence in its three dimensions.

Levels	Cognitive reflection		Emotional consciousness		Behavioral assessment	
	N	%	N	%	N	%
Low	43	23.63	40	21.98	44	24.18
Medium	50	27.47	76	41.76	78	42.86
High	89	48.90	66	36.26	60	32.97
Total	182	100	182	100	182	100

3.2 Specific Objective 2.

To determine the perception of sexual harassment in the dimensions of gender qualification, denial of rights and gender image among university students in Sullana, shown in Table 2.

Table 2. Level of perception of sexual harassment in its three dimensions.

Levels	Generic qualification		Denial of rights		Gender image	
	N	%	N	%	N	%
Low	42	23.08	41	22.53	44	24.18
Medium	80	43.96	63	34.62	92	50.55
High	60	32.97	78	42.86	46	25.27
Total	182	100	182	100	182	100

3.3 Specific Objective 3.

To identify the beliefs that justify sexual harassment among university students in Sullana.

Response of first cycle university students (Table 3) to the questions:

(A) "Sexual harassment occurs because one allows it".
(B) "The majority of complaints of sexual harassment are false".
(C) "Women are sexually harassed because of their provocative way of dressing".
(D) "Men would not be affected in the least by a situation of sexual harassment".
(E) "It is impossible for an acquaintance to harass you".

Table 3. Response values of questions about beliefs.

Question	(A)		(B)		(C)		(D)		(E)	
Quantity	N	%	N	%	N	%	N	%	N	%
Agree	54	30	44	24	30	16	37	20	35	19
Disagree	128	70	138	76	152	84	145	80	147	81
Total	182	100	182	100	182	100	182	100	182	100

3.4 Specific Objective 4.

To determine the relationship between the conception of violence and the perception of sexual harassment among university students in Sullana.

For this objective, the Kolmogorov-Smirnov normality test was applied, by the number of the sample, in order to determine the origin of the distribution of the data, that is,

Table 4. Normality test of the perception of the conception of violence and the perception of sexual harassment, with the dimensions of each variable.

		Cognitive reflection	Emotional consciousness	Behavioral appraisal	Generic rating	Denial of rights	Gender image	Violence	Harassment
	N	182	182	182	182	182	182	182	182
Normal parameters a,b	Media	16.22	15.19	11.81	9.91	6.49	12.97	43.23	29.37
	SD	3.555	3.262	2.500	2.201	1.641	2.570	7.966	5.571
Maximum extreme differences	Absolute	0.153	0.139	0.144	0.178	0.205	0.119	0.158	0.117
	Positive	0.144	0.078	0.101	0.171	0.179	0.119	0.097	0.117
	Negative	−0.153	−0.139	−0.144	−0.178	−0.205	−0.115	−0.158	−0.112
Test statistic (KS)		0.153	0.139	0.144	0.178	0.205	0.119	0.158	0.117
P. value		0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
	N	182	182	182	182	182	182	182	182

if they come from an asymmetric distribution or normal distribution, and then choose a correlation test (parametric or non-parametric), according to Table 4.

According to the significance level ($p < 0.05$), all dimensions have an asymmetrical distribution, so Spearman's correlation coefficient is applied to relate the variables, shown in Table 5 and Table 6.

Table 5. Relationship between the perception of the conception of violence and the perception of sexual harassment among university students in Sullana.

		Perception of sexual harassment							
		High		Medium		Low		Total	
		N	%	N	%	N	%	N	%
Conception of violence	High	27	14.84	28	15.38	1	0.549	56	30.77
	Medium	20	10.99	57	31.32	12	6.593	89	48.90
	Low	0	0.00	9	4.94	28	15.38	37	20.33
	Total	47	25.82	94	51.65	41	22.53	182	100

Table 6. Results of the correlation between the perception of the conception of violence and the perception of sexual harassment, with the dimensions of each variable.

		Generic qualification	Denial of rights	Gender image	Harassment
Cognitive reflection	Cc*	0.547**	0.527**	0.491**	0.598**
	Sb*	0.000	0.000	0.000	0.000
Emotional Consciousness	Cc	0.657**	0.543**	0.448**	0.642**
	Sb	0.000	0.000	0.000	0.000
Behavioral assessment	Cc	0.579**	0.519**	0.387**	0.563**
	Sb	0.000	0.000	0.000	0.000
Violence	Cc	0.705**	0.620**	0.511**	0.707**
	Sb	0.000	0.000	0.000	0.000

* Cc = Correlation coefficient, Sb = Sig. (bilateral).
** The correlation is significant at the 0.01 level (bilateral).

3.5 Specific Objective 5.

To propose a psychoeducational intervention program based on the ecological model, according to the conception of violence, to eradicate sexual harassment among university students in Sullana, as shown in Fig. 1.

4 Discussion

When analyzing the three dimensions of the conception of violence held by university students in Sullana, it was found that in the cognitive reflection dimension, 23.63% is located at a low level, reflecting that even a minority percentage of university students have diffuse concepts about the term violence. In the emotional consciousness dimension, a low level equivalent to 21.98% can be evidenced, indicating that the emotions generated by violent episodes are not recognized. In the dimension: behavioral assessment, corresponding to a low level of 24.18%, there is evidence of a lack of knowledge of acts or behaviors considered as violent, which could be justifying direct and structural violence. Regarding the three dimensions of the variable perception of sexual harassment, the generic qualification has found a significant percentage of students in the low level, 23.08%, which reflects that the concept of sexual harassment is not clear. In the dimension: denial of rights, we found 24.18% of university students in the low level, indicating that they do not recognize that acts of sexual harassment violate human rights. Finally, in gender image, the low level of 24.18% shows that students do not recognize that sexual harassment behavior is the result of gender roles established in society. These results explain why young people of this generation present stereotypes on issues of gender violence, so it is necessary to restructure thoughts and generate adaptive attitudes.

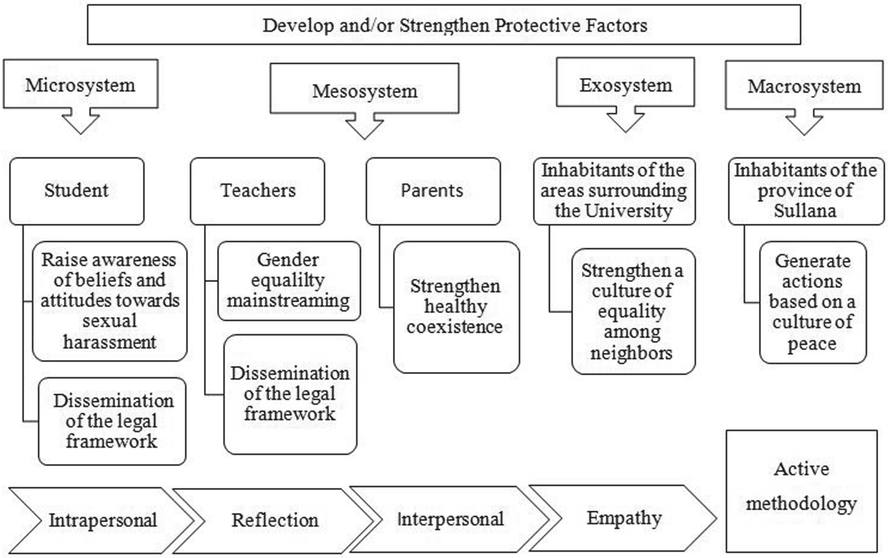

Fig. 1. Intervention process to eradicate sexual harassment from the ecological model.

When identifying the beliefs that justify sexual harassment in university students, we found that those that reach a percentage higher than 15% approval are: "Sexual harassment occurs because one allows it", "Most reports of sexual harassment are false", "Women are sexually harassed because of their provocative way of dressing", "Males would not be affected in the least by a situation of sexual harassment" and "It is impossible for an acquaintance to harass you".

5 Conclusion

A relationship with positive direction is evident, strong in most of its dimensions and with a significance level ($p < ,05$), which indicates that both variables are closely linked i.e. strongly associated and respond to a pattern in such a way that the proposal of the intervention process from the ecological model if applied under this context the expected altruistic results can be achieved.

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Does Being Human Cause Human Errors? Consideration of Human-Centred Design in Ship Bridge Design

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Abstract. 75%–96% shipping accidents involved human-error in 2018 [1]. One of the most critical reasons was poor design of controls and lack of proper procedures [2]. It is unclear if ship-bridge design entirely considers user experience (UX). The crews are working in an increasingly time/resource pressured industry. Especially when hazardous scenarios occur, the increased amount of information being processed and decreased available time for decision-making together make it error-prone, adding an extra complexity to UX. Investigating the extent to which design influences human-error and distracts people from task's reality, this paper evaluates the overlooked aspects of ship-bridge design to understand if it distorts user's reality in hazardous situations and increases high cognitive loads with complex interfaces. Considering human-centred marine design (HCMD) that deals with end-user, addresses issues by adopting human factors/ergonomics (HF/E) introduced in industrial design, and applying product semantics/semiotics to the bridge design, reducing high cognitive loads with ergonomic interfaces.

Keywords: Human error · Human-centred design · Human factors · Cognitive ergonomics · Product semantics

1 Introduction

Contemporary ship systems are technologically advanced & highly reliable however, 75–96% of marine casualties are still caused by some form of human-error [1]. Grech pinpoints that despite technological advancements, inadequate design is responsible for approximately one-third of all accidents [4]. Rothblum argues that while human-errors are too often blamed on "inattention" or "mistakes" on the part of the operator, more often than not they are symptomatic of deeper and more complicated systematic problems, human-errors are generally caused by technologies, environments and organisations which are incompatible in some way with optimal human performance [1]. In the most instances, human-error is the result of inappropriate design of equipment or procedures, Norman believes that the poor design of the controls, lack identification of proper procedures by crews, in particular the lack of a Safety Management System is most

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often the culprit. In many cases, a human-centred design (HCD) effort could eliminate most errors [3]. Current ship bridge lacks consideration of UX in workplace/equipment design, which rarely offers consistent user interface design across numerous systems that seafarers interact with.

HCD is commonly applied in industry design as a multi-stage problem-solving process. It improves not only aesthetics & functionality of a product/system, but HF solutions to enhance the performance of users interacting with interfaces. In contrast to Human-Centred Industrial Design, Marine Design, i.e. naval architecture, addresses a well-informed design specification. Effective Marine Design requires a multidisciplinary design team of naval architects, industrial designers, HF specialists, environmental psychologists & interior designers. Therefore, the Human-Centred Marine Design (HCMD) process will start from understanding the personas and needs of the end user. The objective of HCMD within the context of this investigation is to study both function and form, and the connection between vessels' bridge equipment, users, and the environment. The benefit is to improve safety and reliability to reduce the risk of further accidents by anticipating emergency situations at the early stages enabling decision making clearer and more efficient. This paper reviews current ship-bridge design, studies HCMD method and HF theory, and discusses design solutions for future ship bridge. This paper presents a funded project conducted so far and offer initial fundamental insights for future discussions.

2 Human-Centred Design

HCD is an approach to systems design/development, making interactive systems more usable by focusing on the use of the system and applying HF/E and usability knowledge/techniques. It also refers to a process that places the human needs and limitations in a higher priority compared with other objectives within the design process. Where designers required not only to analyse/generate solution for existing problems, but test/validate the products/service to achieve proposed targets in the real world [5]. HCD consists of four defined activity phases: A) Identify the user and specify the context of use; B) Clarify the user requirements; C) Generate design solutions; and D) Assess design solutions against requirements [6,7]. The core of HCD is to enhance the usability of products, to maximise user satisfaction and to promote the safety performance of the device. HCD has been adopted to shipbuilding that incorporating task analysis into the ship bridge design. Vessels such as cruise ships and private yachts are prime examples of HCMD to bridge layouts that have benefited OOW. HF principles are in routine use in other industries & have shown that human-error can be controlled through HCMD. The maritime industry needs to follow suit to ensure HCMD and evaluation [1].

3 Reviewing Current Ship Bridge Design

Many types of human-errors which were shown not to be the "fault" of the human operator. Most errors tend to result of technologies, work environments and organisational factors which do not sufficiently consider the abilities and limitations of the people who interact with them, thus "setting up" the human operator for failure. In other words, the human is expected to adapt the system, which does not work. Instead, the system should adapt the human [1]. Norman agrees that we must stop being so technology-centred and become human-centred [2]. Rothblum continues that human errors can be reduced significantly by HCMD. Applying HF to understand human capabilities & limitations, the HCMD will increase efficiency/effectiveness, decrease errors, accidents, and personnel injuries [1]. However, current ship design models are technology-centred that do not consider the ship's operation as part of the design process. Gernez [8] highlighted the lack of seafarers' participation in the design process, but he also demonstrated the benefit of implementing effective usability testing. Thus, form design or styling activities are often reduced to a discussion based on opinion and subjectivity, with no theoretical basis [9]. In most cases, shipbuilders focus primarily on physical ergonomics and research seated wheelhouse cockpit designs which integrate equipment solely around anthropometrics, such as the line of sight and reach allows information to be more accessible for the OOW.

The market presents various design solutions through different manufacturers to provide vessels with various technologies & interfaces independently. Currently, the responsibility for equipment selection relies on the ship owner's personal experience and preference. In terms of HCMD, it reduces the effectiveness of success through not considering key users. Mallam speculated that one reason for the large variety of digital interfaces is the lack of regulations in this area [10]. Grech et al. listed lack of standardisation as one of the main human-machine interaction (HMI) issues onboard ships, and lack of usability, information overload and ergonomics integration in design [4]. From the design perspective, standardisation will reduce errors and facilitate familiarity and work tasks, i.e. the standardisation of systems across ships/ship types, lifeboats, safety equipment. The harmonisation between bridge interfaces will eliminate unnecessary repetition, make functions more integrated and compatible, such as the example of the Integrated Bridge Systems that have been developed by a number of manufacturers [12]. Research indicates that consistency in user interface design directs the user in transferring skill in using one system to another. It is also connected to usability, efficiency and reduced error rate [11]. Design consistency can be defined across many components of a user interface (UI) and spatial organisation of components, colours, symbols and typography. It also relates to aspects of interaction design, the structure of content, user interface patterns and interaction mechanisms.

4 Addressing Human Error Through Human Factors

The nature of human error is subjective; operators have different levels of ability and behavioural attributes to cope with the complexity, pressures and workloads when completing watchkeeping tasks in emergency and non-emergency situations. Within the literature on human error, three perspectives currently dominate. Norman's error categorisation [13], Reason's slips, lapses, mistakes and violations classification [14] and Rasmussen's skill, rule and knowledge error classification [15]. Galieriková discovers that most failures are not the human operator's fault, but of organisational factors, technologies and work environments. Therefore, it is critical to consider the operator's organisational factors at an early design research stage rather than by reviewing the existing accidents [16].

HF is the scientific discipline that concerned people to understand interactions among humans and other elements of a system, and a profession that applies theory, principles, data and methods to design in order to optimise human well-being and overall system performance [17]. The IEA (International Ergonomics Association) designates different domains of focus within the discipline, namely physical ergonomics, cognitive ergonomics, and organisational ergonomics among others [18].

'Physical ergonomics' concerned with physiological/biomechanical characteristics, human anatomical and anthropometric as they relate to physical activity [19]. The relevant topics include working postures, materials handling, repetitive movements, screen display angles/distence, equipments position/dimensions, bridge layout, OOW activities, safety and health in the bridge.

'Cognitive ergonomics' concerned with mental processes, such as perception, memory & reasoning as it affects interactions among humans and system [19]. The relevant topics include mental workload/stress, decision-making, skilled performance, human-computer interaction, human reliability that relates to human-system design. In particular, 'product semantics', the study of symbolic qualities of man-made shape, in the cognitive & social context of their use. It presents a new awareness in design and recognises that people do not respond to the physical qualities of things but act on what they mean to them [20, 21].

'Organisational ergonomics' concerned with the optimisation of socio-technical systems, organisational structures, policies, and processes [19]. Relevant topics include communication, crew resource management, work design/systems, teamwork, virtual organisations, telework/quality management, cooperative work and microergonomics, new work programs, human/organisational factors and office architecture. The maritime sector currently attempts to reduce human error through training and regulations. It is a critical practice in such a complex industry, however, it may have inadvertently increased cognitive load on seafarers interacting with bridge systems & interfaces. Organisational impact on workflow structure of bridge operations can increases/decrease the pressure where human machine interaction (HMI) affect decision making on the bridge.

Given these, industrial designer expects to work on all three levels of ergonomics, to understand the potential occurrence, to ensure the design satisfies the OOW requirements, thereby, minimising human error. It is critical to treat all stakeholders equally using HCMD and usability testing methods to identify users' requirements to the system. Taking account of the whole bridge operation as one product will minimise a wide range of errors.

5 Preleminary Results and Findings Discussion

This paper applies the HCMD method to optimise ship bridge design through development of the ergonomic interfaces to provide control with a low cognitive workload, so as to enhance the performance and ease decision-making. A range of user-centred participatory methods are proposed for data collection; to include tasks observations, behavioural mapping, prototyping & usability testing. 12 structured interviews were completed at the early stage of the research that supplies initial factors/drivers for the development of a conceptual model. The participants included watch keeping officers, a marine police officer to senior marine accident investigators, NDE specialists, HF expert, academic researchers and bridge simulation lecturers. The findings confirm an agreement amongst the participants that human-error contributes to almost every maritime accident in addition to resulting from incorrect operation of electronic aids or due to fatigue, information overload or unfamiliarity with the equipment [24]. So, attributing accidents to human error 'alone' is a fallacy [29]. However, a single human error hardly explains it fully, it is connected with operational process, cognitive demand, organisational factors [28]. Moreover, most people (92%) believe regulation plays an important part in reducing accidents. 42% recommend good design will improve UX. 33% relied on training and 25% think alarm system is essential. Communication, mechanical controls, navigation equipment, especially standardisation of interface are options to reduce accident. In addition, classification of human-errors benefits future ship configuration (83%) that helps the design to achieve optimal performance [31]. Ultimately, everyone agrees that decision making is affected in highly pressured situations and causes errors.

Half of the participants believe that the findings from current human-error research have been effectively implemented in bridge design. However, others argue that the research focused on human-error prevention strategies rather than on the bridge design [36]. Thus, there is no real useful knowledge to be utilised if the solution is to 'remove unreliable human' from the system [29]. Bridge equipment manufacturers compete in the same market with their own design variation which leads to a multitude of different bridge equipment layouts [24]. 83% participants state that variations in current bridge design provide very limited workflow consistency for familiarisation with the vessel [26]. Even though, there are some international standards/codes for basic requirements of equipment display but still, every manufcaturer can have their own design variation. Some of them are user friendly but others are extremely complicated [23,26]. Beyond these requirements, simple/direct/coherent display styles would be helpful for seafarers [23]. Moreover, most existing bridges were designed in a conventional way with traditional layout/function/equipment. Therefore, effective workflows with simplest/clearer/direct/logical information are urgently needed [23], although some modern specialised ships have impressive integration of systems/design [30,29]. Almost all experts agree that digitalisation and automation are the most significant changes to ship bridge design over the last decade. Ergonomics consideration in safety/comfort in bridge design was not improved [23], as it takes time for various flag states to agree & put into legislation [24].

Cope outlines four types of critical interfaces for watch keeping officers: 1) Interface with reality-being able to fully see 360°, to hear outside and inside (radio traffic and alarms), and to feel ship's movement and engines. 2) Navigation information in real time (chart information with GPS input, projected passage). 3) Anti-collision information (radar with plotting and AIS information). 4) Course, rudder angle, speed [24]. This has repeatedly been shown from most feedbacks and with extra suggestions to inlcude information from ECDIS, ARPA, VHF, BNWAS and steering control equipment. In addition, many suggest a dedicated conning display but with the proviso that: A) No information overload and simple switching of views. B) Critical information would have priority (alarms would override the view). C) No two views can be so alike as to be mistaken i.e. the viewer shuold always be able to identify which view is being displayed to ease interpretation of information at sea [24,23]. In contrast, others worried that the conning might be confusing [28, 31], clutter the screen with lots of irrelevant information [25, 26] and over complicate the process [32]. Having numerous display styles & bridge equipment variations affect the level of cognitive absorption [24, 28], it can result in lack of attention, fatigue, or being overwhelmed with information [27, 31].

Design skills are transferable to bridge system design, if the designer has some sort of sea experience [26] or input from seafarers during the design process [28,24]. Some designers follow general ISO HCD standards [29] alongwith international rules for ship construction [27, 33]. Implementation of basic HMI design principles would improve bridge design significantly [29]. Designers focus on system icons, colours and pointers, providing ease of recognition to aid seafarers operating bridge controls [40], if they bind tightly with seafarers to achieve effective & safe design [30]. Simple HMI design inputs and consistency across systems are a massive step in the right direction for bridge design [29]. However, symbol standardisation is only successful where it is mandated by International Governmental Organisations [24].

The literature review on the subject suggests that errors are considered as arising largely from an inability to make sense from a mismatch of meanings and affordance. Thus, the attribution of blame for such errors shifts from users to designers who largely are responsible for the interfaces in which these errors arise [21]. Incorporation of design input from the OOWs in the design phase of shipbuilding supports the implementation of field studies in ship design [8]. This highlights the limitations on the ship designers creating systems without considerable input from the end-users. Other issues affecting marine design is the variance in bridge equipment design styles between manufacturers. Understandably, each manufacturer implements their design considerations based on their own system design preferences. However, design expands the notion of usability with participatory methods to design objects that catering users' needs in an inclusive & collaborative, co-constructed manner [22].

The findings of the primary research (analyses of interviews results from domain experts) corresponded with the outcomes of secondary research. All participats agreed that attributing accidents to human error is a fallacy. Previous research placed great emphasis on human-error prevention strategies rather than bridge design. Thereby, current technology-centred bridge design offered very limited opportunity for a standardised familiarisation with the vessel. The future bridge design expects to focus on UI design that targets to ease watchkeeping officer fulfiling OOW duty.

6 Conclusions

HF recommendations identify industrial designers play a crucial role in future ship bridge design. The skills possessed by industrial designers supply them with greater understanding of the end-users demands due to HCMD and participatory strategies. The significance of this research is to instruct the industry away from a technology-centred to human-centred design that takes account of 'form follows meaning'. The primary data collected from domain experts reveals that physical ergonomics has benefited modern specialised ship design achieving OOW requirements. Further, simple HMI design inputs and consistency across systems are the right direction for bridge design [29]. Emphasising on the cognitive ergonomics in interface design will further reduce human-errors occur. Meaning is given from experience. If design can transfer successfully people's previous knowledge/experience to the new interface created, it will reduce users' cognitive workload and enhance crews' performance. Future work in this research will be developing this theory to create a physical conceptual model which will lead to a comparative assertion of the interface across all bridge systems, allowing to baseline the best configurations. Furthermore, the data collected from this research will be used as an informative tool to guide future work for 1) a virtual conceptual prototype of an intuitive/ergonomic ship bridge that satisfies the users' needs/desires, for seafarers to work more comfortably, effectively and safely in the event of an emergency and reduces training needs and manages workflow more effectively. 2) an optimised conceptual framework for future ship bridge design that narrows the gap between UX at sea & design thinking; especially, for manufacturers when developing new products/equipment in the future. The findings hence provide the essential foundation for new design specifications for next generation of bridge designs. It will be particularlly important when taking into account the fast devleopment of autonous ships.

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Reflections of the Different Reasons for not Teleworking

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Abstract. The objective of this paper was to analyze the reflections of the different reasons for not teleworking on important aspects such as organizational commitment, intention to leave, job satisfaction and burnout. Most existing literature does not look at the different reasons for not teleworking. Four companies with different teleworking practices were selected and two phases survey were carried out. In the first phase, an interview was conducted with the human resources area to obtain information about the telework practice. In the second phase, questionnaires were emailed to all their employees to collect their perceptions: 632 questionnaires were answered, 249 from non-teleworkers. Strong evidence was found to the relationship between employees who were not allowed to telework and greater burnout and intention to leave and lower organizational commitment and satisfaction. The paper shows the importance of a good eligibility process and training for managers.

Keywords: Home office · Organizational commitment · Job satisfaction · Exhaustion at work · Intention to leave · Telework · Telecommuting · Burnout

1 Introduction

There are many reported benefits and barriers of telecommuting in recent research and literature on business, employees and environment. The main cited barrier to the adoption of teleworking is management [8, 15]. Managers concerns about possible impacts on work environment [9]. Some managers also fear losing organizational commitment when a telework request is not granted [14].

The objective of this research was to evaluate the reflexes of the different reasons for not teleworking on organizational commitment, satisfaction, exhaustion and intention to leave the company.

In 2019, four companies with different teleworking practices were selected and two phases survey were carried out. In the first phase, an interview was conducted with the human resources area to obtain general information about the telework practice adopted. The second phase was quantitative. Questionnaires were emailed to as many employees as possible. 632 questionnaires were answered, 249 from non-teleworkers.

Strong evidence was found regarding the relationship of employees who were not alowed to telework with lower organization commitment and satisfaction and greater

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intention to leave and exhaustion. The lack of managerial support for the practice was also related to greater exhaustion and lower satisfaction. This study shows the importance of training for managers to deal with those excluded from the telework program.

2 Organizational Commitment

In the 1990s, Meyer and Allen [11] proposed a model for organizational commitment with three dimensions and has been the most referenced in the literature.

a. Affective commitment: refers to the employee's emotional attachment to the organization. The employees continue in the organization because they want to do so.
b. Continuance commitment: refers to an awareness of the costs associated with leaving the organization. The employees remain because they need to do so.
c. Normative commitment: reflects a feeling of obligation to continue employment. The employees feel that they ought to remain with the organization.

Meyer and Allen [11] explain that "an employee can experience all three forms of commitment to varying degrees". The three forms of commitment will have a reducing effect on the employee's intention to leave [11]. An employee with a strong affective commitment is more likely to exert a greater effort on behalf of the organization than the other commitment dimensions [11].

3 Telework

In this study, we considered as teleworkers the individuals who are full or part time employees of an organization and who perform at least some of their work from a remote location rather than at the workplace or head office using technology to interact with others as needed to perform work tasks [4].

The telework has been shown in the literature as an attractive way of working because it provides benefits to employees and the company. Despite all the potential advantages for organizations and employees, the telework has encountered many challenges. Mahler [10] analyzed management challenges especially in relation to employees who do not practice telework. Their study suggests that the benefits of telework may be perceived as unfair by conventional workers. This raises the possibility of discontent among those who are not allowed to telework with impacts on job satisfaction and performance. Caillier [5] investigated the impact of telework on company intentions to leave and motivation. Unauthorized employees for telework were more likely to leave the organization than employees who did telework or who did not telework for technical reasons, job requirements or personal preferences. Caillier [5] also found employees without permission to practice telework with lower levels of motivation when compared to frequent teleworkers or other workers. Caillier [6] suggests that equity theory may help to understand why those who chose not to telework expressed levels of satisfaction much closer to teleworkers than those who were not allowed to telework but wanted to do so.

4 Methodology

The objective of the research was to evaluate the impact of the different reasons for not teleworking on important organizational indicators: affective, normative and continuation commitment, intention to leave, job satisfaction and burnout.

In a first step, a bibliographic research was carried out to analyze what already exists in the scientific environment, relating telework to commitment, satisfaction, intention to leave the company and burnout.

In the second step, the script for the interviews and the questionnaire for quantitative research were prepared. The interview script sought to gather general information about the telework practice adopted in the companies. The quantitative research questionnaire was elaborated based on instruments already validated in the literature. Even so, the questionnaire underwent a pre-test with a group of five people to verify the clarity of their understanding in Portuguese and then a pilot test was performed with 30 answers to validate their internal consistency through the Cronbach's Alpha test.

In the third step, four organizations that adopt different teleworking practices were chosen and interviews were conducted with those responsible for the human resources.

In the fourth step, a questionnaire with objective questions and multiple-choice answers was sent to all workers of the selected companies. The questionnaire was prepared in Google Forms® and made available to the research target population in electronic format, via email or business social networks.

In the fifth and final step, the levels of commitment, satisfaction, intention to leave and burnout of employees who work in a traditional way were compared according to their reasons for not teleworking through multiple linear regression analysis.

4.1 Definition of Variables and Research Measuring Instruments

In the terminology of regression analysis, the predicted variable is said dependent variable. The variables used to predict the value of the dependent variable are called independent variables [17].

The independent variables are related to some work profiles and the reasons for not teleworking:

– I don't do telework because I have no interest
– The kind of work I do require my presence in the office.
– My manager doesn't allow me to work from home or elsewhere, even though I can complete at least some of my work outside the office.
– My manager or company does not support telecommuting in general

The dependent variables considered in the research were: Affective, Normative and Continuance Commitment, Intention to leave, Job satisfactory and Burnout. Scales already widely used and validated in the literature were used to collect the dependent variables, as shown in Table 1: The answers to the questionnaires were based on the five-point Likert scale, with the extremes "strongly disagree" and "strongly agree".

Table 1. Literature scales used.

Item	Scales used
Burnout	General Burnout Questionnaire (Schaufeli, Leiter & Kalimo, 1995) scale
Intention to leave	Based on Abrams, Ando & Hinkle (1998) scale
Job satisfaction	Michigan Organizational Assessment Questionnaire Job Satisfaction Subscale (MOAQ - JSS) (Cammann, C., Fichman, M., Jenkins, D., & Klesh, J., 1979)
Affective, continuance & normative commitment	19-item scale by Meyer & Allen (1997), adapted to portuguese by Nascimento et al. (2008) and Medeiros (1998; 2003; 2005)

Invitations to participate in the quantitative survey containing the questionnaire link were sent by the email or social business network. For each surveyed company a different link was sent to discriminate the answers of each company.

The Likert scale is generated by summing or averaging the answers to the various questions that make up the scale. The data obtained in the field research were analyzed using the multiple regression model using the Excel® software. Multiple regression analysis is the study of how the dependent variable relates to two or more independent variables [17, p. 565].

After multiple regression analysis, two tests were performed: F-Test and t-Test t. F-Test is is performed to determine if there is a significant relationship between the dependent variable and the set of all independent variables, it is a global significance test [17, p. 581]. On the other hand, the t-Test is an individual significance test and is used to determine which independent variables are significant [17, p. 581]. In the Excel® software used, the global significance (Test F) is presented as significance F and the individual significance of the independent variables are presented by the p-value of each. 95% significance was adopted.

For each dependent variable, two regressions were performed. The first regression considers all independent variables. To refine the results obtained in the first regression, a second regression was performed considering only the independent variables that presented p-value equal to or less than 0.10. The results of this second regression with p-values lower than 0.05 were considered significant.

5 Field Research

The surveys were conducted in four companies from September 2018 to February 2019. Table 2 presents the main characteristics of the samples collected in each company.

Table 2. Characteristics of the samples collected.

	IT company	R&D company	Telecom company	Tire factory
Company type	Public	Public	Private	Private
Size	Large	Medium	Large	Large
Telework extension	5 days a week	2 days a week	1 to 4 days a week	1 day a week
Sample characteristic				
Sample size	255	68	243	66
Teleworkers	99	52	175	57
Non-teleworkers	156	16	68	9

6 Results

For each employee perception, in addition to the regressions with the data collected in the IT Company and Telecom Company non-teleworkers group, regressions were performed on a composite basis with the data from the four companies together, represented in the tables with the label "Together".

In the regressions, the independent variables of profile and the "Reason for not teleworking" were considered. In the following sub-items the results obtained for each aspect considering only the independent variables that presented p-value equal to or less than 0.10 inj the first regression. The results of this second regression with p-values lower than 0.05 were considered significant.

6.1 Affective Commitment

Table 3 presents the regression for affective commitment. The results indicate a relationship between those employees who were not allowed to telework and lower affective commitment when compared to other nonteleworks. This result was obtained in the regressions performed with the data obtained with the four companies surveyed.

Table 3. Refined regressions - affective commitment.

Regression results	IT company		Telecom company		Together	
Independent variables	Coefficient	P-value	Coefficient	P-value	Coefficient	P-value
Not allowed to telework					−0.3157	**0.0124**
Company time	0.2717	**0.0000**	0.1870	**0.0383**	0.2098	**0.0000**
Kind of work			0.5370	**0.0102**	0.1822	0.0841
Inability					−0.1146	**0.0001**

These results reinforce the evidence obtained in Cailler (2012) research, where employees who were not allowed to telework reported lower levels of motivation when compared to others non-teleworkers.

6.2 Continuance Commitment

Table 4 presents the regression for continuance commitment. results indicate that employees who were not allowed to telework reported lower continuance commitment. This result was obtained in the regressions performed with the data obtained from the IT company.

Table 4. Refined regressions - continuance commitment

Regression results	IT company		Telecom company		Together	
Independent variables	Coefficient	P-value	Coefficient	P-value	Coefficient	P-value
Not allowed to telework	−0.3776	**0.0241**				
Kind of work			−0.3307	**0.0284**		
Overload	−0.0658	0.1056			−0.1003	**0.0007**
Inability	0.0782	0.1212	0.0624	**0.0487**	0.0937	**0.0040**
Company					−0.1211	**0.0189**

6.3 Normative Commitment

Table 5 presents the regression for normative commitment. The results indicated that employees who were not allowed to telework (Telecom Company) reported lower normative commitment, in relation to the other reasons. Meanwhile, workers who do not telework because of their work requires presence (IT Company), reported higher normative commitment.

Table 5. Refined Regressions - Normative Commitment

Regression results	IT Company		Telecom Company		Together	
Independent variables	Coefficient	P-value	Coefficient	P-value	Coefficient	P-value
Work requires presence	0.3100	**0.0179**				
Not allowed to telework			−0.4623	**0.0031**		
Company Time	0.2018	**0.0004**			0.1227	**0.0026**
Overload					−0.0665	**0.0075**

6.4 Job Satisfaction

Table 6 presents the regression for job satisfaction. The results have indicated that employees who were not allowed to telework reported lower job satisfaction. This result was obtained in all regressions performed. There was also evidence of a negative relationship between lack of management support for telework and satisfaction. These indications were found in the Telecom Company.

The results reinforce the findings made by Mahler [10] that suggest that the benefits from the practice of teleworking may be perceived as unfair by conventional workers.

Table 6. Refined Regressions – Job Satisfaction.

Regression results	IT company		Telecom Company		Together	
Independent variables	Coefficient	P-value	Coefficient	P-value	Coefficient	P-value
Manager does not support			−1.0008	**0.0256**		
Not allowed to telework	– 0.4072	**0.0389**	−0.9066	**0.0001**	−0.6173	**0.0000**
Company time	0.1395	**0.0202**				
Overload	−0.0943	**0.0187**			−0.0637	0.0798
Inability			-0.0777	0.0853	−0.1013	**0.0116**

6.5 Intention to Leave

Table 7 presents the regression for intention to leave. The results obtained in the regressions with the base composed by all the companies together indicate that employees who were not allowed to telework reported higher intention to leave work. The results reinforce the research by Caillier [6] who found significant differences in intentions to leave the company between employees who were not allowed to telework and others non-teleworkers.

Table 7. Refined regressions – intention to leave

Regression results	IT company		Telecom company		Together	
Independent variables	Coefficient	P-value	Coefficient	P-value	Coefficient	P-value
Not allowed to telework	0.4016	0.0845			0.5171	**0.0007**
Overload					0.1557	**0.0000**

6.6 Burnout

Table 8 presents the regression for burnout. The results have indicated that employees who were not allowed to telework or had no manager support reported higher burnout level. The lack of managerial support was significant in the regressions with all companies together and IT Company. The lack of permission was evidenced in the regressions with all companies together and Telecom Company.

Table 8. Refined regressions - burnout.

Regression results	IT company		Telecom company		Together	
Independent variables	Coefficient	P-value	Coefficient	P-value	Coefficient	P-value
Manager does not support	0.4422	**0.0374**	1.2615	0.0757	0.4962	**0.0162**
Not allowed to telework			0.8079	**0.0240**	0.5521	**0.0058**
Kind of work			−1.0053	**0.0049**	−0.4494	**0.0071**
Overload	0.4343	**0.0000**	0.2987	**0.0032**	0.4265	**0.0000**
Inability	0.2516	**0.0041**	0.1897	**0.0473**	0.2287	**0.0001**

7 Conclusions

Table 9 summarizes the reflections of the different reasons for not teleworking. The highlight is for the employees who were not allowed to telework, questionnaire option: "My manager doesn't allow me to work from home or elsewhere, even though I can complete at least some of my work outside the office". The research has shown strong indications as to the relationships of this reason with higher levels of burnout and intention to leave and lower satisfaction and affective, continuance and of normative commitments.

Table 9. Influence of profiles on worker attitudes.

Reasons for not teleworking			Reference/New fiding*
Work requires presence	Greater	Normative Commitment	New
Manager does not support	Greater	Burnout	New
	Lower	Satisfaction	New
Not allowed to telework	Greater	Burnout Intention to leave	New Cailler, 2013b
	Lower	Affective Commitment Continuance Commitment Normative Commitment Satisfaction	Cailler, 2012 New New Mahler, 2012

*New finding in relation to the literature researched by the first author.

The survey results have indicated the relevant impact of the employee's different reasons for not performing the practice.

There are several practical implications of this result, such as the establishment of a clear policy for the implementation of a telework program, a detailed communication plan and the training of managers to deal with employees excluded from the telework program.

The ability to do work at home or nearby leads to another quality of life and facilitates the inclusion of people with physical disabilities in the labor market. However, the results of this study show the challenges of managing in this new organizational setting. There is no doubt that telework creates new complexities in workplace dynamics for all, managers ans employees.

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Psychological Impact on Design: Empirical Case Studies in City Regeneration of Post-industrial Sites

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Abstract. Industry restructuring are pressures faced by cities in both the East and West. Some successful Chinese examples do not consider the distinctive characteristics of local and demand for experience from people. Nowadays, people expect more than just function in their chosen environment but benefit from interaction, connection and engaging the senses. Good Human-Centred Emotional Design (HCED) generates not only happiness and but also a sense of security and safety. Empirical case study was used as a means of human-centred research, to explore the contribution of psychological factors in post-industrial sites regeneration. Applying Norman's concept of three levels of design as a tool, this paper will examine whether the designs offered at current renovation projects satisfy visitors' expectation, in terms of visceral appearance, experience of interaction with environment and finally the psychological satisfaction of people. Thereby, to clarify how can architectural/environmental psychology and emotional design theory enhance the design.

Keywords: Human-centred design · Architectural psychology · Emotional design · Urban regeneration · Post-industrial sites · Qualitative research

1 Introduction

In the phase of human-centred design (HCD) driven industry, the design tends to concern higher level of human needs; architectural space is endowed with more senior psychology significance [1]. Fully satisfying people's demands increasingly becomes a focal point of design research; thus, an increasing number of architects and designers place great emphasis on HCD, in particular at the psychological and emotional level. Contemporary design expects to offer the user with advanced experience, where emotion appears to be a pervasive quality that serves to shape an experience [2]. In order to improve users experience, satisfying their psychological and emotional demands will be crucial. Therefore, designers need to establish the relationship amongst the architectural, environment and emotional experiences, and how to employ architectural function as an emotional lever in user experience. Many regeneration projects have done well commercially in providing

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retail and entertainment spaces and facilities, however, have performed poorly in satisfying visitors' experience expectation and psychological demands. Given the above, this paper focuses on exploring emotional and psychological impact on design, and construction issues in urban regeneration. Employing empirical case studies as a HCD method, the redeveloped post-industrial site in Beijing, China and in Liverpool, the UK have been investigated, aimed to outline the psychological impact on the regeneration of post-industrial sites.

2 Aim and Objectives

The aim of this research is to inspect if environmental psychology and HCD inform the environmental/architectural design in city renewal projects. The focus emphasises on enhancement of visitors' experience through design. The aim will be achieved through, 1) understanding the principles of environmental psychology and emotional design and their applications in urban regeneration; 2) Outlining successful applications of environmental psychology in architectural design and urban planning/regeneration.

3 Human-Centred Emotional Design and Environmental Psychology

Shifting from the technology driven to human-centred design driven phase, design now has entered a new chapter. Increasingly, designers realise that satisfying people's the psychological demands is essential, as design services human beings rather than objects. Referring to usable, meaningful, and enjoyable design, HCD is defined as a group of methods and principles that emphasises on how to acquire/apply knowledge about people and their interactions with the environment, so as to design products that meet their needs and expectations [3]. Integrating user's perspective into the architectural design process to achieve better user experience [4], In general, industrial buildings appear being closed due to the single purpose of production and inherent stereotypes, showing an indifference temperament [5]. Therefore, it is necessary to break the stereotype of industrial buildings in the regeneration process by using HCD as a tool that enables the user to interact and communicate with the building and environment.

HCD is practised in its most basic form, making design physically, perceptually, cognitively, and emotionally intuitive [6], therefore, we describe the contemporary design as Human-Centred Emotional Design (HCED). HCED concerns how user perceive the design result, their interaction with the building and living experiences, rather than focusing on project developers, designers or other stakeholders. Current HCED tends to shift focusing from users' physical and cognitive characteristics to emotional engagement and pleasure experiences [7–9]. The research method of HCED aims to collect more data with a variety of backgrounds, such as cultural exploration, aimed at enlightening design practitioners [10]. Based on the analysis of the information process between the user and design outcome, Norman [8] introduces the concept of 'three levels of design' as: the visceral, behavioural and reflective designs. The visceral level refers to the physical attributes of the design, whereas the behaviour level inclined to human behaviours and focusing on the function and user experience. The reflective level is the function of the first two levels, which investigates deeper needs and aspirations of a human. It is a complex emotion intertwined with a variety of factors such as the product's personal consciousness, experience and cultural background [8]. Likewise, understanding people's emotional demand in urban design, HCED expects to enhance users' experience.

The human-environment relationship is symbiotic which indicates that the environment influences humans' behaviours and humans in turn influence the environment [11]. Proshansky [12] defined Environmental Psychology as to study of the interaction and relationship between humans and their environment. The emergence of Environmental Psychology indicates that people begin to notice the significance of the physical context of human behaviour [13]. Architectural Psychology is a branch of Environmental Psychology, an interdisciplinary subject between psychology and architecture. Architectural Psychology does not only require human ideology to permeate every link of building formation, but also seeks to analyse the influence of quantitative factors such as architectural form, space and colour on human psychology [14]. Users' psychological demand is directly related to the quality of space. The core of architectural psychological research is to explore individual response to the environment and to create a desirable place to survive, so as to satisfy individual psychological demand. In this process, each person perceives the real built environment as a stimulus condition and reacts to it, after that, forms psychological activities and behaviours on the built environment, and finally evaluates the environment. The evaluation results provide a reliable basis for environmental design.

4 Methodology

In accordance with the objective and research questions raised in this study, location-based research method has been employed to form the basis of this research, to explore the contribution of psychological factors on post-industrial sites regeneration. The qualitative empirical case study has been utilised as a means of human-centred research approach, to achieve the research goal of gaining deeper insights into urban regeneration.

1. Location-based walking interviews. Several field trips have been made to the two locations seeking visitors' responses and expectations of the renovation. This immersive approach effectively helps the study of visitors' perception towards the targeted environments and captured the lived experience of users. Also, reviewing tourists' comments published on the specialized websites has been considered as an alternative research method in this study.
2. Customer' comments from published websites. After a comparative research in seeking reliable resources, 'TripAdvisor.com' was selected due to its reputation as one of the most popular sources of travel information in the world. 'Dianping.com' is a leading platform for local life information that holds a large number of users in China. Likewise, 'mafengwo.cn' is another Chinese travel social website, where users share travel strategies and experiences. Meanwhile, in order to undertake a proper and effective analysis in this study, a smart data analysis program was developed to focus particularly on generating statistical data based on the information published on these websites.

3. The assessment criteria. Norman's theory of three levels of design provided an assessment criterion that can examine if a product satisfies the users' expectation and at certain levels. In this research, this concept was employed as an evaluation tool to measure whether the designs offered at the two renovation projects satisfy visitors' demand, in terms of its visceral appearance, experience of interaction between the users and the environment, and finally the reflective level of satisfaction of people. So as to clarify how can architectural/environmental psychology and emotional design theory enhance urban regeneration, in particular the redevelopment of aged factory site. Accordingly, the findings of these two case studies will be of great significance and value for future research, in terms of which provided a research exemplar of both cultures.

5 Comparative Case Studies

5.1 Beijing - 798 ArtDis

The 798 ArtDis is one of successful post-industrial regeneration projects that is featured as a typical Chinese example. As a former electronics factory, it was closed in 2001 due to economic decline. Now, 798 ArtDis has attracted many artists that are settled in the park due to its low rent and distinctive architectural style. Currently, 798 ArtDis is a home of art gallery, artist studios, design companies, restaurants, and bars. Having recently accessed the websites Dianping.com and Mafengwo.cn, there are total 19449 comments was reviewed, 2106 negative feedbacks that reveal some issues and expectations from the tourists' perspective. The redevelopment of 798 ArtDis appears to succeed at the visceral level, in terms of its architectural appearance design [15]. And efforts have been made in industrial heritage retention and distinctive concept creation. Featured with extensive spaces and widely positioned columns, most buildings retain the original Bauhaus style, for example the reservations of initial staleness slogans and abandoned facilities/instruments, so as offering visitors with a great visual impact and presenting a sense of the vicissitudes and changes of history. Following the Bauhaus style, namely the concise keynote, which is reflected in the spatial image, colour, material and other aspects. The abandoned pipes of former factory are set off by lighting and glass, so that creating a unique artistic atmosphere with the superposition of industry and art [16].

The data pinpoints that 798 ArtDis won an excellent reputation in retaining the industrial buildings successfully, showcasing its history and traditional Chinese culture. The park attracts tourists in providing innovative design solution to highlight its distinctive characteristics, supplying functional demands and commercial services. Being positioned as a cultural and creative industrial park, 798 ArtDis targets its audience are bourgeois and fashionista, therefore, most tourists enjoy taking photos and then uploading them to social media to manifest their artistic taste and identity. The deficiency of reflective design is mainly embodied its over-commercialisation and diluted cultural factors, which influence its targeted position. This has been proved by 584 negative reviews which is about 89% of the visitors blamed that 798 ArtDis like a shopping centre - full of restaurants, clothing stores, cafes and dessert shops. However, the artistic atmosphere is not strong [17].

Other negative comments such as the lack of spatial planning which results to heavy traffic flows appear to concern most visitors. There are no public signs to distinguish footpath, pedestrians and/or carriage road within the park, therefore creating serious safety issues during the visit. 71% visitors complain that it was dangerous when walking on the street, as people and vehicles share the same road and street within the park [18], thus tourists have to be aware of traffic safety at all times. Moreover, many sharing-bikes are left after use, which occupies public space [19]. Drivers also blame the traffic signs which are poorly designed, causing the driver, for example driving in from the west gate to follow the sign heading to car park, however losing direction and exiting out through the south gate accidentally [20]. In addition, many one-way streets do not present clear instructions, which is prone to traffic jams and led to honking. Consequently, noise pollution causes further problems that decline the level of visitors' satisfaction.

Weak infrastructure results to a number of public services offered in 798 ArtDis are insufficient. 68% visitors blame that the park does not have enough public toilets. Services for disabled appear to be even worse. "My grandmother has limited mobility, so that requires using a wheelchair. When we intended to enter the park, however the gate had restrictive barriers that blocked the wheelchair in getting through" [21]. People complain that as a famous scenic spot, 798 ArtDis attracts a large number of tourists each year, however the poor infrastructure created obstacles that impeded its business development.

5.2 Liverpool - Albert Dock

Officially opened by Prince Albert in 1846, Liverpool Albert Dock has been the largest port in Britain, and represented the successful implementation of urban regeneration [22]. The Dock was abandoned in 1920, due to its incapacity to meet the requirements of rapid development of commodity trade and shipbuilding technology. Albert Dock has become one of the most popular heritage sites in Britain, which is at the forefront of Liverpool's cultural consciousness [23].

On 28 December 2020, a total of 17,517 reviews displayed on TripAdvisor.com which consists of 16508 positive reviews and 1009 negative reviews. It is undeniable that Albert Dock has the inherent advantage of integrating the urban landscape and natural scenery. The vast Mersey River has endowed the dock with indescribable charm. The architecture of Albert dock is distinctive as well. The regenerated Albert Dock maintains the original layout, roof and colour of the original building [24]. The warehouse is enclosed along the dock and the layout is rectangular. The warehouse is topped with a cast-iron frame and a black roof. The bottom is cast iron Doric colonnade, which is red echoes the wall, and there are load-bearing arches between every 3 or 4 columns, some hydraulic machinery (fasteners, hydraulic arms, etc.) kept in place between colonnades [25]. The overall visual effect of the buildings is aesthetic and rhythmic. The boiler and winch preserved on the dock are part of the outdoor sculpture that is the constant reminder of the dock's bustling past.

Deferring from Beijing 798 ArtDis, the regeneration of Albert dock was well organised and planned in terms of traffic flows, construction of parking spaces and business services provision. Data indicates that 89% - a total 110 reviews, rated its public facilities and infrastructure positively. The dock's traffic flow is reasonably planned, where the pedestrian viewing path is not interfered by traffic. The pedestrian flow of different functional areas is not interwoven, and the common space and facilities are separated as far as possible in terms of time [26]. In addition, the dock area has convenient parking, rest and dining conditions, and a clear route indication system [27], which carefully considers the visitors' feeling and significantly improves visitors' experience. Meanwhile, there are 40 people which accounts for 70% of positive reviews for disability services. The dock has also constructed multiple toilets for the disabled [28] and wheelchair access [29]. As a tourist resort, the dock provides multiple tourist functions, such as boating, canoeing or surfing, and visiting museums, galleries, and souvenir shops.

The regeneration successfully integrated the city's history and culture into the dock [30]. The most successful aspect of Albert dock regeneration is transforming the industrial site becoming a part of the city and integrates it into lives of the locals. Furthermore, the regeneration of the docks embodies the spirit of urban, the project does not only promote the development of commercial but also fundamentally serves the locals. The Albert dock combines the cultural characteristics of old buildings with modern fashion, finding a way between historic heritage and new cities.

6 Discussion

The results of the secondary and primary research conducted in this project pinpoint that regeneration projects' user value local history, industrial heritage, and art activities. People enjoy innovative, fashion and distinctive design solution, and desire the opportunities to interact with objects and the environment they are living. They also expect the regeneration projects can create extra entertainment recourses and public facilities in city transformation. Contemporary HCED can create new demands on public services, not only helps people in articulating their functional needs and behavioural/interactive demands, but also achieving their best sense of living - 'the reflective goals' as efficiently and effectively as possible. The finding of the comparative case study indicates that both two projects appear to satisfy users' demand at the visceral level, in terms of providing innovative design solutions, respecting/preserving industrial heritage and cultural value. However, 798 ArtDis seems dissatisfy visitors' infrastructural needs in terms of smooth traffic, easy parking, pedestrian safety, and disability assistance; therefore, failed at the behavioural consideration and further the reflective level of design. In contrast, Albert Dock not only performs well commercially in supplying a variety of new public services and cultural heritage places of interest but also offers satisfying infrastructural facilities. The renovation immerses audiences into its history, which triggers the human senior psychology and reflective experience.

The statistical data collected based on the source of TripAdvisor.com, Dianping.com and Mafengwo.com certified that the positive feedback rate (94%) of Albert Dock is higher than 798 ArtDis (89%). This is due to the fact that the redevelopment of the Albert Dock was carried out under the guidance of MDC and thus had a consistent purpose [24]. Diversity of development does not mean clutter, planning/organisation of the dock was finalised by the developers after a series of feasibility analyses such as entertainment and transportation. In contrast, the development of the 798 ArtDis is spontaneous without unified planning, which lacks behavioural design. In addition, the Albert Dock takes geographical advantage of the waterfront to preserve the dockyard group and warehouse completely, turning it into a huge outdoor exhibition hall, successfully continuing the maritime culture and incorporating more cultural elements. The successful experience of the Albert Dock provides new ideas for the preservation and regeneration of the industrial heritage.

7 Conclusions

Given the discussions, it can be concluded that human psychology & emotion influence design. Architectural/spatial design have undergone rapid change in terms of renovation expectation from multiple stakeholders. People not only fancy the physical appearance of an environment and enjoy its cultural experience provision, but also expect interactive opportunities offered at the renovation, which clearly reflects the expectation of the full three levels of HCED design. Utilising psychological and emotional knowledge as factors in environmental design will inform the design of an urban regeneration project and to enhance user experience. With the continuous improvement of people's life, monotonous design is no longer enough and will be upgraded by something of a higher level, namely emotion [8]. To meet people's spiritual needs, design is endowed with more emotional significance. The methodologies employed in this study for gathering data are thought to be reliable based on its consistency. However, the results of the research may not be generalised due to which only two case studies have been undertaken. A future research into a larger sample size will benefit the research to ensure obtaining a more solid conclusion. This project investigated the psychosocial impact on urban design, especially redevelopment of aged industrial zones. The findings expect to contribute a broad scope of beneficiary, i.e., the architectural/environmental designers, to create distinctive & advanced design solutions in urban regeneration that to break the existing cookie-cutter design.

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Effect of Color Weight Balance on Visual Aesthetics Based on Gray-Scale Algorithm

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Abstract. This paper analyzes and studies the color weight balance value based on the weighting rule of gray-scale algorithm, explores the combination of color beauty measurement and planar visual aesthetics evaluation, discusses the effect of color weight balance on the visual aesthetics, and evaluates the matching experiment through image processing. The data fits the curve of the relationship between the balance of color weight and visual aesthetics, and it provides a basic reference for the quantitative evaluation of the aesthetic quality of human-computer interaction interfaces. In the end, it is proved that the color weight balance has positive effect on visual aesthetics and it is also affected by other surrounding conditions.

Keywords: Gray-scale algorithm · Color weight · Balance · Visual aesthetics

1 Introduction

The purpose of this paper is to explore the impact of the change of the color weight balance value based on the gray-scale algorithm on the visual beauty of the plane. The main research content combining the theory of design, psychology and algorithmic knowledge with practice, and combining perceptual design with analysis of psychological laws, preliminary experimental research on visual aesthetic evaluation from the perspective of color quantification. Secondly, the paper combines the grayscale algorithm with the color weight balance, and it obtains the fitting relationship between the color weight balance change and the visual aesthetics through experiments, which proves that the interface color weight balance quantification is roughly consistent with the interface visual aesthetics search results. Therefore, the result in this article has certain reference value for the visual aesthetic evaluation of the human-computer interaction interface.

2 The Influence of Color Weight Balance on Visual Beauty

Color is the direct form in the transmission of visual information. Different colors have different psychological effects on people with strong visual impact based on their experience. Weight perception refers to people's ability to perceive the weight of objects. According to related papers, color can affect people's ability to perceive the weight of

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objects. Objects of the same weight will give people different weights due to different colors, and different individuals will have different weight perceptions for different colors [1] (For example, the white in the light color makes people feel that the object is lighter, and the black in the dark color makes the object appear heavier). This is the influence of the psychological effects of color on the process of object weight perception. The theory shows that the change of hue and chromaticity has little effect on the sense of color, and the perception of color weight is more focused on the difference in color brightness [2]. It can be obtained that the weight of the color is mainly related to the difference of color brightness, the color with high brightness has low weight, and the color with low brightness has high weight [3].

Although color weight and brightness mentioned by CIE (International Commission on Illumination) are different categories of concepts, this may be proved to be an empirical fact by the existing data. The bottom line for the application of this concept is to select an appropriate operating definition [4].

From the perspective of interface optimization design, when improving the layout and design of elements in the interface, Changing the brightness of the color to adjust is very helpful, such as increasing the brightness for a large area, and reducing the brightness for a small area to achieve a visual equalization effect, so that the overall visual effect of the interface is more unified and harmonious [5]. Balance is one of the principles proposed to describe how to group perceptual elements into recognizable whole objects or "good forms" [6].

These existing theories and studies illustrate the importance of maintaining the overall balance of elements in visual perception and it can quickly guide the viewer to look at the image. In the current research, the equilibrium point is obtained by adding the visual moments in the horizontal and vertical directions to zero at this point. The balance refers to the relative balance between up and down and left and right between the various parts of the element. The equal and unequal shapes can also achieve a balanced effect. Equilibrium is a special form of symmetry [7].

Whether each element in the interface can achieve a visual balance depends on the influence and weight of the attributes of each design element in the interface, such as the overall layout of the interface, the shape and color of each element, etc. [5]. Ngo et al. stated: The balance of the interface refers to the accumulation of the overall balance of the elements in the horizontal and vertical directions in the interface, and the overall balance which is called BM can be expressed by the following formula [8]:

$$\mathrm{BM} = 1 - \frac{|\mathrm{BMvertical}| + |\mathrm{BMhorizontal}|}{2} \in [0, 1] \tag{1}$$

BMvertical and BMhorizontal represents the accumulation of the overall balance of all elements in the vertical and the horizontal direction. The BM in the two directions is expressed by the following formula:

$$\mathrm{BMvertical} = \frac{\mathrm{WL} - \mathrm{WR}}{\max(|\mathrm{WL}|, |\mathrm{WR}|)} \tag{2}$$

$$\mathrm{BMhorizontal} = \frac{\mathrm{WT} - \mathrm{WB}}{\max(|\mathrm{WT}|, |\mathrm{WB}|)} \tag{3}$$

$$Wj = \sum_{i}^{nj} Wij \tag{4}$$

L, R, T, and B represent the numbers of the left and right parts of the interface color weight value, so Wj represents the weight of part j of the interactive interface; Wi represents the color weight value per pixel unit of the interface [8].

Therefore, the quantitative conversion model of color is to calculate the color weight value by extracting the change of color brightness. This paper proposes the preliminary concept of color weight balance to evaluate the model to bring usability suggestions to the interface visual aesthetic evaluation and design.

3 Balance of Color Weight Based on Gray-Scale Algorithm

In the color weight quantization, the color image can be converted into an grayscale image with only brightness difference to calculate the color weight Balance degree.

3.1 Color Image Gray-Scale Algorithm

Color is composed of three basic colors: red, green, and blue. The three primary colors are divided into 0–255 levels, a total of 256 color levels, and the image combined according to the different levels of the three colors will get a true color RGB image [9]. The three colors channels can be divided into 256 levels of brightness. The brightness is weakest at 0 and the strongest at 255. When the three-color brightness levels are all 0, it is the darkest black tone. When the three-color brightness levels are all 255, it is the brightest white tone [10]. The gray value of each pixel in the gray image can also be a linear sum of each dimension of a point in the RGB color space, but a weight coefficient is added to each dimension. Therefore, the grayscale of color image is the mapping from three-dimensional space to one-dimensional space [9] (Fig. 1).

Fig. 1. RGB color diagram

In an RGB image, if R = G = B, the color is called a grayscale color. The extraction of the brightness of each primary color into grayscale requires a certain method to convert the three values of R, G, and B [9]. The three primary color components of any pixel (a, b) of the input color image are marked as Rn(a, b), Gn(a, b), Bn(a, b), assuming grey(a,

b) is the gray level of the corresponding point value. According to related papers, the value of grey(a, b) can be showed as the formula by the weighting method:

$$\text{grey}(a, b) = WR * Rn(a, b) + WG * Gn(a, b) + WB * Bn(a, b) \quad (5)$$

WR, WG and WB are the weights corresponding to Rn(a, b), Gn(a, b), and Bn(a, b) respectively [10].

According to the sensitivity of the human eye to the channel, assign different weights to the brightness values of the R, G, and B channels to calculate the gray value of the image. Green is the most sensitive to the human eye, and blue is the least sensitive, so when giving the corresponding weights, it should satisfy $G > R > B$. According to psychological theory and related experimental research, when $WR = O.299$, $WG = 0.587$, $WB = 0.114$, grayscale images that conform to the laws of human visual psychological perception [11]. There is an rgb2gray function in the MATLAB to convert the three-dimensional color value into one-dimensional gray value weighting. The formula is:

$$\text{grey}(a, b) = O.299 * R(a, b) + O.587 * G(a, b) + 0.114 * B(a, b) \quad (6)$$

The grayscale algorithm of color image with fixed weight is a more general method to deal with the grayscale problem of color image. Its advantages are small amount of calculation and strong adaptability, which is more suitable for simple RGB color image grayscale occasions [10].

3.2 Calculation of Color Weight Based on Gray-Scale Algorithm

According to human psychological effects, the gray value of black color is 0 which is heavier and the gray value of white is 255 which feels lighter, so it can be concluded that the weight of the color is inversely proportional to the gray value of the color, so as to infer that the color weight value is the reciprocal of the color gray value:

$$W(a, b) = 1/\text{grey}(a, b) \quad (7)$$

3.3 Color Weight Balance Calculation

It can take the visual aesthetic evaluation of the plane poster interface as an example to evaluate the color quality balance. The sample gray scale processing and color weight balance calculation are all done with Matlab based on the formulas.

The selected eight sample images are as follows. First, they are all subjected to 5*5 pixel blur processing and then grayscale processing. Finally, the color weight equalization values are calculated respectively. The results are shown in the following figure (Fig. 2).

There are the segmentation of the upper left, upper right, lower left, and lower right parts of the sample and the overall color weight balance value (Table 1):

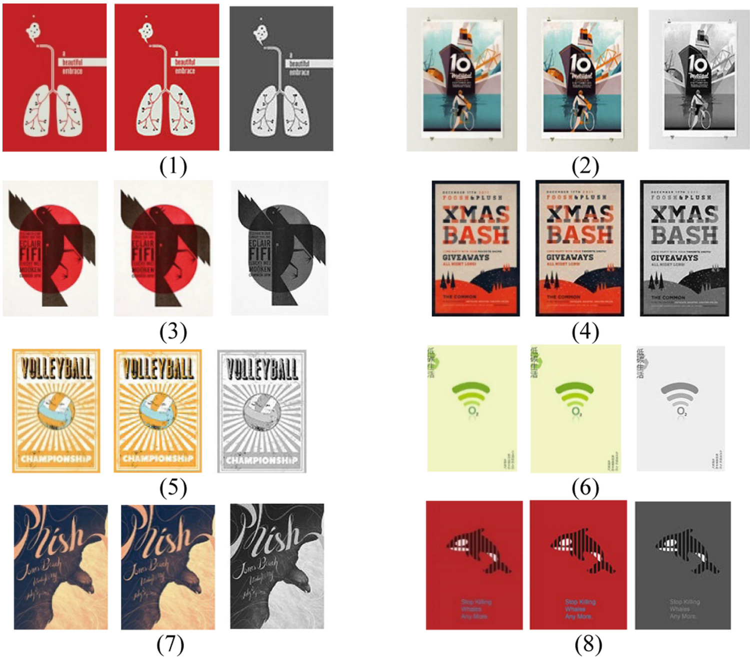

Fig. 2. Eight groups of samples

Table 1. The segmentation of eight samples and the overall equilibrium value

Upper left	Upper right	Lower left	Lower right	Value
(1) (140*100) pixel				0.8739
				
(2) (174*134) pixel				0.9222
				
(3) (180*130) pixel				0.9603
				
(4) (170*110) pixel				0.8551
				
(5) (140*100) pixel				0.9563
				
(6) (190*134) pixel				0.9669
				
(7) (160*120) pixel				0.7085
				
(8) (160*120) pixel				0.9699
				

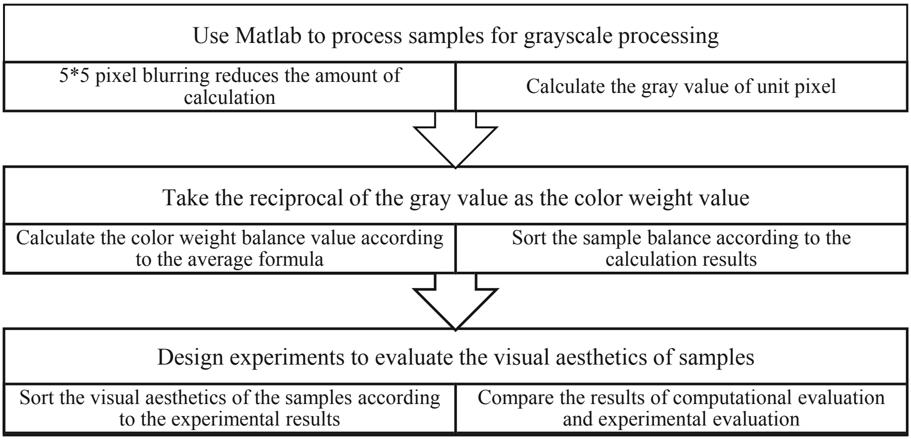

Fig. 3. The research method framework

3.4 Summary of Research Method Framework

See Fig. 3.

4 Design Experiment

It is important to design the experiment to explore the effect of color weight balance on visual aesthetics. The subjective evaluation is used to sort the visual aesthetics of the experimental samples and compare with the color weight equalization value calculated above to study whether the color weight balance based on the gray-scale algorithm has a direct impact on the visual aesthetics.

4.1 Experimental Subjects

This experiment recruited 20 people (10 males and 10 females) to conduct experiments. Participants were young people aged 20–25, who were not color-blind. To ensure the reliability of the experimental data, the subjects were randomly selected from the group of students and social workers. The experiment was no payment.

4.2 Experiment Process

The sample pictures were distributed to the subjects for subjective evaluation, and the subjects were told to sort the sample numbers in the order of best seen.

5 Results

According to the calculation of the ranking result data of all subjects, the beauty evaluation values of the 8 samples are 0.79, 0.90, 1.03, 0.85, 0.82, 0.94, 0.75, 1.12, respectively. The subjective evaluation of the sample's visual beauty comprehensive evaluation sequence number (from high to low) is 8 3 6 2 4 5 1 7. The color quality equalization values of the eight samples calculated above are 0.8739, 0.9222, 0.9603, 0.8551, 0.9563, 0.9669, 0.7085, 0.9699, and the sorted number (from high to low) is 8 6 3 5 2 1 4 7. It can be seen the overall sorting trend has a constant tendency.

6 Data Analysis

The subjective visual aesthetic evaluation value obtained from the experiment and the calculated color weight balance value are data-fitted through matlab to obtain the relationship between the plane visual aesthetics and the color weight balance value change, as shown in the following figure (Fig. 4):

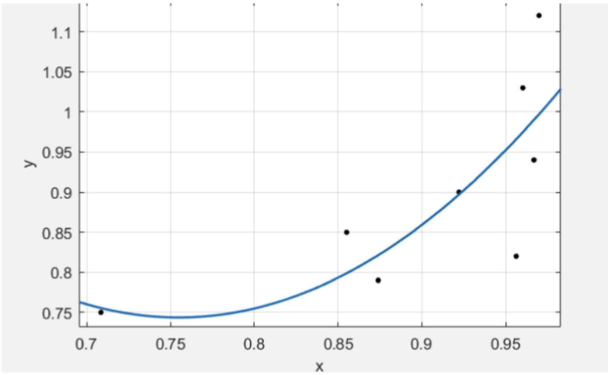

Fig. 4. The fitting curve of color balance and visual aesthetics

The function relationship is:

$$Y = 5.47X^2 - 8.27X + 3.86 \quad \left(R^2 = 0.59\right) \tag{8}$$

X represents the color weight balance value, and Y represents the visual beauty of the image. It can be seen from the figure that the visual beauty and the color weight balance value are generally positively correlated, and the fit is good.

7 Discussion

Due to limited experimental resources and capabilities, there are inevitably theoretical or experimental flaws in the article. The evaluation of visual aesthetics should not only consider the balance of color quality. Therefore, the influence of various surrounding factors should also be considered. In short, the relationship between the color weight balance and visual aesthetics should me discussed in the future.

Acknowledgements. This study was supported by the foundation items: The National Key Research and Development Plan (No. 2019YFB2006402).

Appendix: Experimental Raw Data

See Table 2.

Table 2. The result data of eight samples sorted by 20 subjects

Subjects	Aesthetic ranking
Luo (male)	61257348
Ji (male)	78631524
Niu (male)	56312487
Wei (male)	68351427
Che (male)	27483561
Jia (male)	87234516
Liu (male)	86315247
He (female)	24381567
Gao (female)	47318526
Fang (male)	32451867
Wang (female)	84521367
Hao (female)	63185742
Luo (female)	26473581
Ping (female)	85631427
Zhang (male)	82347651
Jing (female)	73816542
Yue (female)	65183427
Tang (female)	81372456
Yang (male)	62483157
Chen (female)	78425631

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Improving Physical Activity with a Data-Analyzing Smart Insole that Assesses Root Causes of Chronic Pain and Physical Inactivity

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Abstract. Chronic lower body pain is a pervasive problem in the United States and globally. People with flat feet are more likely to experience plantar fasciitis, Achilles tendonitis, calluses, corns, blisters, bunions, hammertoes, shin splints, among many other ailments. If untreated, these issues may develop into more serious injuries and chronic pain. Physical inactivity due to chronic pain predisposes to a cluster of metabolic diseases. Low-fit individuals especially benefit from increasing physical activity. LAAF - *Live Active and Agony Free* - addresses the important role of physical activity in reducing mortality risk for individuals with chronic pain by enabling a healthy and active lifestyle. LAAF insoles provide comfort and support while analyzing gait, improving posture and alignment, and tracking fitness metrics. Data from the insoles is compared to normative gait data using algorithms to create user-specific reports in real-time. The LAAF mobile app connects users to caregivers, articles, and personalized exercises. Monitoring of these parameters is essential in the management of chronic pain and sedentary lifestyle. Management and prevention of chronic foot pain using current standards of care methods remains a challenge. LAAF Inc. has developed a smart wearable device with a mobile app to monitor and manage chronic pain as an effective strategy in reducing foot pain and increasing physical activity.

Keywords: Smart insoles · Chronic pain · Internet of things · Wearable device · Physical inactivity · Gait cycle

1 Introduction

Physical inactivity is increasing in the US and it is one of the leading causes of preventable deaths accounting for approximately 365,000 (15.2%) deaths, in the year 2000 [1]. The

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percentage of US adults who regularly engage in the recommended amount of leisure-time exercise is estimated at approximately 30.7% [2]. Researchers predict that the combined effect of physical inactivity and poor nutrition will soon surpass smoking as the leading cause of preventable death [3]. Worldwide, 1 in 4 adults and 3 in 4 adolescents (aged 11–17 years) do not meet the physical activity standards set by the World Health Organization (WHO) [4, 5]. Higher levels of physical fitness lead to improved health outcomes [6–8]. Additional studies show that just 15 min of exercise per day can lead to a reduction in mortality and 3 years of increased life expectancy [9, 10]. Of 80% of people with regular foot pain, 51% said their activities were restricted most notably in walking, standing, and exercising, according to a 2014 study by the American Podiatric Medical Association [11].

80% of Americans experience foot pain each year, with 40% suffering from heel pain [12]. A study in the United Kingdom found that a third of men and a half of the women surveyed have admitted to wearing shoes that do not fit [13]. Some of the most common reasons for foot pain are poorly-fitting shoes (unsupportive), standing for long hours (overuse), and displaced foot pressures (misalignment). Feet alignment varies over time with changes in weight, age, pregnancy, or chronic disease [14]. The consequences for misalignment include common foot ailments, such as bunions, blisters, hammertoes, neuropathy, and improper gait. Flat footed adults, which make up 8% of the total US population (18 million people), are more likely to experience foot pain and associated foot ailments [15].

Improper gait is not easily visible. However, the effects of improper gait can impact the entire lower body, not just the foot. Improper gait affects the kinetic chain of the body, which is the interconnected checkpoints in the body responsible for movement from the feet and ankles through the legs and knees to the hips and even the lower back. Existing solutions improperly address the unique alignment in each foot, access to quality care and evidence-based information. This may lead to over-reliance on pain-killers and self-medication [16]. Gait and movement abnormalities can be identified and users can be coached to improve their posture, cadence, and alignment based on their unique data. Smart insoles can be used to help sufferers avoid injuries in the form of calcaneus fractures, Lisfranc dislocations, chronic plantar fasciitis, chronic lower back pain and worsening knee osteoarthritis. Implanting sensors in the insoles can help one identify, through walking patterns, development of some of the aforementioned disorders and recovery progression via machine learning [17]. There is much room for integrated research in studying the remedial effects of using smart insoles with inbuilt sensors, barometers, and inertial measurement units.

There is a paucity of studies regarding the effects of wearable devices to empower patients with chronic lower body pain and reduced physical activity. Research on existing smart insoles shows that existing products that offer smart insoles are mostly geared towards athletes and specific sports [18]. Although not an insole, Sensoria has created a sock that can monitor activity. The prices for Digitsole, Arion, and Sensoria range from $200–$300. Wiivv, which is now called FitMyFeet, costs $100 for a custom 3-D printed insole that does not include any data tracking capabilities. Plantiga focuses on injury recovery and is sold to health providers and organizations. Salted insoles are for golfers to improve their golf performance by showing weight distribution and balance throughout the golf swing. Success of these companies show that incorporating technical components into an insole is possible. Each of these products include Inertial Measurement Units and/or pressure sensors within the insoles. It is also important to note that only Digitsole and Salted insoles have their technical components embedded into the insole, whereas Sensoria and Arion require externally attached pods in order to be effective.

LAAF believes that a smart wearable device with a mobile app to monitor and manage chronic pain is an effective strategy in reducing foot pain and increasing physical activity. We have embedded technical components into insoles to collect data and compare to normative datasets. Users may opt to receive a signal when their parameters are in the abnormal range for self-management. Based on user data, LAAF provides personalized recommendations of curated literature, helpful exercises, and connections to expert caregivers in our mobile application for comprehensive management. Users may book in-person or remote telehealth appointments with local licensed providers, highly rated personal trainers, physiotherapists, and foot specialists using the map feature in the LAAF app. Studies indicate that using mobile health to monitor chronic disease, with mutual feedback between users and caregivers, leads to improved health outcomes [19].

2 Materials and Methodology

We performed an extensive literature review, detailed analysis of existing smart insole products and expert panel discussions with a team of embedded systems engineers, and materials engineers. Sensors were evaluated for accuracy, resistance to extremes of temperature and humidity. Materials for the insoles were microscopically examined and tested for resilience and durability. A mobile application was devised with a team of software designers with mobile app user interface and user experience developers. A standard protocol was devised for validation of precision, connectivity, and transmission with data from the 1000 norms project, which defined the concept of 'normal' as it relates to ambulation and musculoskeletal health [20]. The LAAF insole collects gait cycle data, which is analyzed in the mobile application. This data is presented for a complete analysis of cadence, pronation, supination, acceleration, balance, and pressure on each foot with changes compared to baselines and normative data. Users can opt to receive alerts when these parameters exceed defined thresholds. With these reports, the LAAF app will connect users to personalized solutions to address the root causes of their pain, and access exercises, blogs and articles, as well as schedule appointments with local caregivers specialized in lower body pain.

3 System Development

LAAF Insole Sub System. The block diagram that shows the electronics within the LAAF insole is shown in Fig. 1. The placement of the sensors, flexible printed circuit board (flexible PCB), and the rigid printed circuit board (rigid PCB) in different sections of the foot is shown in Fig. 2.

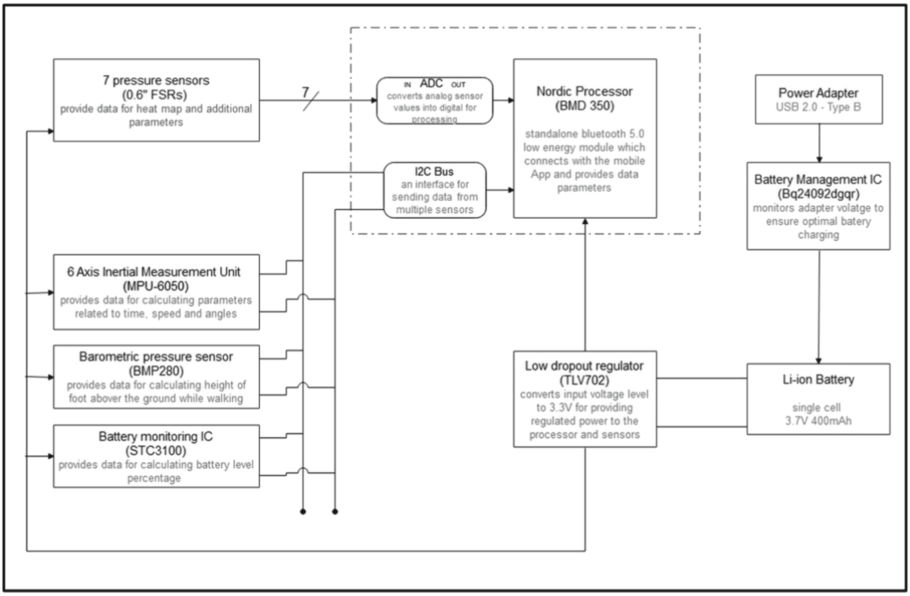

Fig. 1. Block diagram of electronics used in LAAF insoles

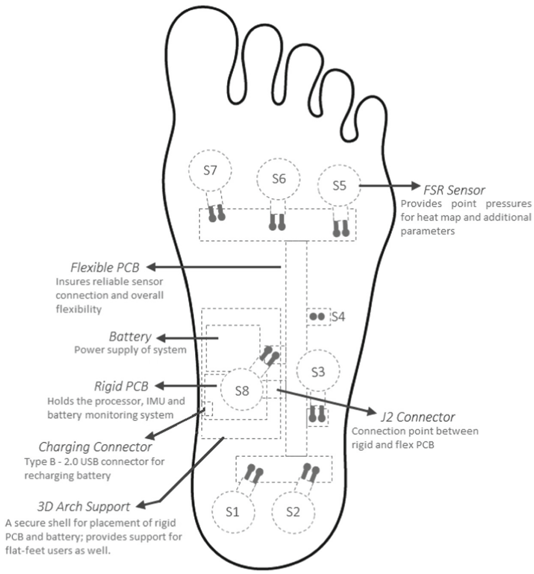

Fig. 2. Placement of FSR sensors in different sections of the foot

Seven pressure sensors are placed in the different sections of the foot to illustrate the pressure distribution with the help of a flexible PCB. These force variations from the pressure sensors, along with other parameters from an inertial measurement unit (IMU) and a barometer, are processed and analyzed within the microcontroller placed on the rigid PCB. Using Bluetooth, the microcontroller sends this data to the application end.

Pressure Sensors. One of the most important parameters in gait analysis is the pressure distribution along the foot. There are multiple sensors used in literature and available in the market that are used to calculate the force applied to a certain area, such as Ceramic Piezoelectric Sensors, Micro-Electromechanical Systems (MEMS) Sensors, and Force-Sensitive Resistor (FSR) Sensors. To make a system effective, simple to use, and cost efficient. FSRs sensors are the best choice among all. Force Sensitive Resistor (FSRs) sensors are used to calculate the pressure applied to the 0.5-in. sensitive bit area. These sensors basically act as the variable resistor whose resistance varies according to the pressure on it. If the pressure increases, then the resistance of the sensor goes down and vice versa. In case if there is no pressure on the sensor then the resistance becomes infinite and the circuit acts as an open circuit. Similarly, if the pressure is less, the resistance becomes approximately 100 kΩ (kilo-ohms) and if there is a maximum pressure on the sensor, then it drops down to a minimum resistance up to 200 Ω (ohms) (Fig. 3).

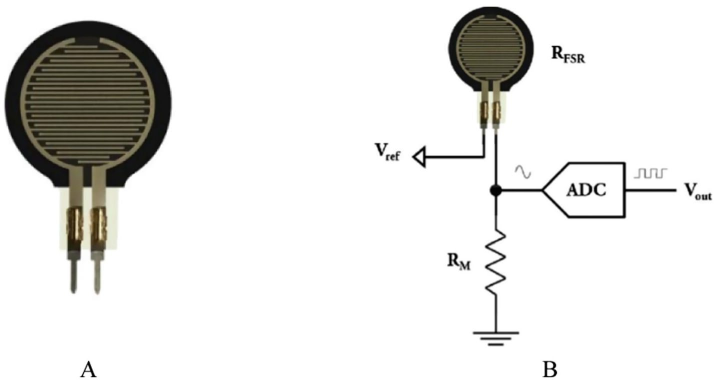

Fig. 3. A. Force sensitive sensor (FSR) and B. FSR sensor as pull-down resistor

These FSR sensors are then used as a pull-down resistor to give input to the analog to digital converter (ADC) pins of the microcontroller for processing to calculate the pressure variations.

Bluetooth Low Energy Module. The LAAF insole uses a System-On-Chip (SOC) Bluetooth module with a microprocessor. This ultra-low-power Bluetooth low energy module can establish communication from multiple peripherals and center point at a time and provide better control over the quality and bandwidth of the transmitting and receiving signal. The module has a 32-bit microprocessor that means this can process 32 bits of data per clock cycle, 512 kb flash, and 64 kb RAM to store and process the application code. Besides this, there are other useful built-in features that can be used in different customized applications.

The LAAF data from multiple sensors are processed within this microcontroller and transmitted to the application end via high-speed 5.2 Bluetooth signals for the treatment of a user. For communication both the insoles act as peripherals that can send data from the user end to the application end which is the central unit. The raw data is analyzed via deep learning and curated to each unique user on its way to the central unit. Later, caregivers can use this data from the insoles that are received in the application end for management strategies (Fig. 4).

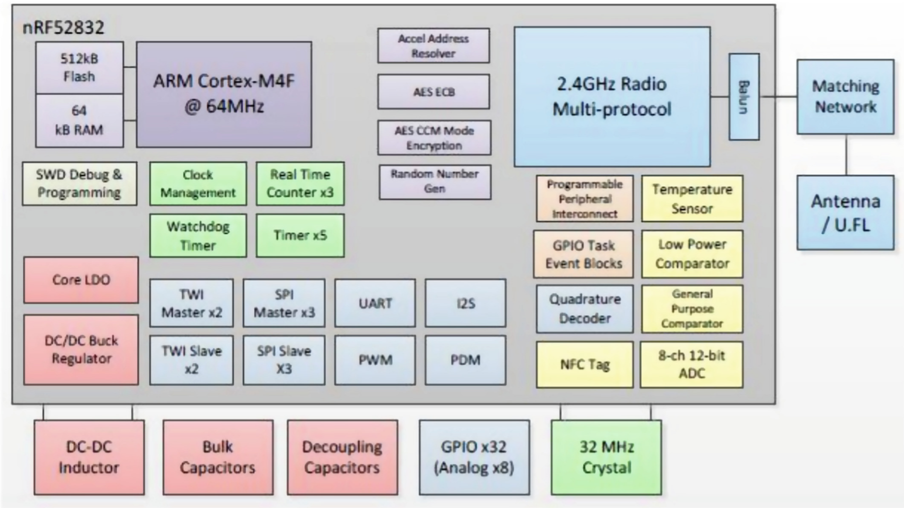

Fig. 4. Black diagram of BMD-350 A-R module

Inertial Measurement Unit. To calculate the motion-related parameters, the 6-axis inertial measurement unit (IMU) is used within the insole that consists of a 3-axis accelerometer and 3-axis gyroscope. With the help of the acceleration and gyroscope

Fig. 5. Peripherals (insoles) communication with central unit (mobile application)

readings along X, Y, and Z axes, the roll, pitch, and yaw values are calculated that change in degrees. These roll, pitch, and yaw values are important to calculate the gait parameters like angle of elevation, pronation/supination, and progression. This IMU interacts with the microcontroller and other sensors with the help of I2C bus (Figs. 5 and 6).

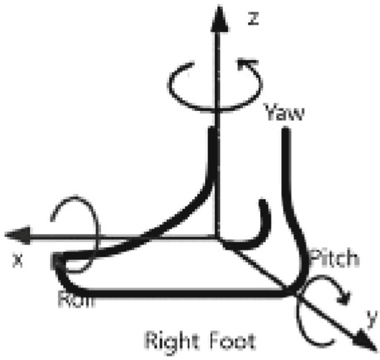

Fig. 6. Roll, pitch and yaw angles for right foot

Atmospheric Pressure Sensor. The barometer sensor is used to measure the atmospheric pressure at a certain height and it is attached to the I2C bus of the microcontroller. The atmospheric pressure reading changes according to the distance above or below the sea level.

Battery Monitoring System (BMS). The complete circuitry of the LAAF insole is powered by using the single cell Lithium-Ion battery (3.7V/400 mAh). To check how much percentage the battery is charged, the rigid PCB has a battery monitoring IC on board. This battery monitoring IC is attached to the microcontroller I2C bus and helps to monitor the instantaneous or real time voltages of the Lithium-Ion battery, which is then converted into a percentage.

In case the battery level is low, the user can charge the insole by using a USB B type cable with the power adapter with a 5 V/0.5 A rating. The battery charging IC has a built-in over-voltage protection support that helps to charge the Lithium-Ion battery with extra care, with required input voltage and current range in three different stages such as conditioning, constant current and constant voltage.

Sensors Used to Calculate Gait Parameters. The table shows the list of gait parameters which are calculated from the sensors used in LAAF insoles (Table 1).

Flow Chart. The flow chart in Fig. 7 represents the complete working of LAAF insole.

Table 1. Gait parameters

■ = Sensors that are used

No.	Parameters	FSR	IMU		Baro-meter	STC
			Acc.	Gyro.		
1	Angle of Elevation (Heel Strike)	■	■	■		
2	Angle of Pronation/Supination (Heel Strike)	■	■	■		
3	Angle of Elevation (Mid stance)	■	■	■		
4	Angle of Pronation/Supination (Mid stance)	■	■	■		
5	Angle of Elevation (Toe OFF)	■	■	■		
6	Angle of Pronation/Supination (Toe OFF)	■	■	■		
7	Angle of Progression	■	■	■		
8	Mid Stance Time	■				
9	Heel Strike Time	■				
10	Toe Off Time	■				
11	Time of Swing	■				
12	Stride Length	■	■			
13	Average Stride Length	■	■			
14	Gait Cycle Time	■				
15	Cadence	■				
16	Speed	■	■			
17	Steps	■	■			
18	Battery Level					■
19	Step Clearance	■				
20	Height Above Ground	■			■	
21	Distance Covered	■	■			

Key for Fig. 7 Flow Chart: Start: Beginning of the Process. Awake Insole from Deep Sleep Mode: Deep Sleep Mode helps save power when the insoles are not in use. The user simply exerts some pressure on the surface of the insole to awake from Deep Sleep Mode. Bluetooth Advertising: Before connecting to the application, the insole advertises itself with a unique Bluetooth name (Left/Right Insole) and 16-bit long service Universally Unique Identifier (UUID). These attributes help to establish the proper connection between the peripheral (insoles) and central point (application). Get Connected: There are two options for whether the user connects the insoles with the application within a given time or not. No: If the connection is not established, then start the timer. Yes: If the user connects the insoles with the application, then start the calibration process. Time > 1 min: If the user is still not connected with the insoles, we have two options: either we can continue Bluetooth advertising, or activate deep sleep mode. No: Time is still less than 1 min, so continue Bluetooth advertising and wait for the user to connect the insoles. Yes: Longer than 1 min without response from a user, so take action. Activate Deep Sleep Mode: Insoles are not in use, so activate a power management mechanism. Calibrate Insoles: It is important to calibrate the insoles according to the user body posture. Before calculating the gait parameters, the calibration redefines the origin of the IMU gyroscope and accelerometer axis. Calibrated: This condition checks whether the insoles are providing error free measurements or not. No: The error is still not removed properly. Yes: Error is removed, and we are ready to calculate gait parameters. Send Calibration Command: If the insoles are not calibrated and providing false data, then the user can simply press a button given in the application to calibrate insoles. Request Data: The LAAF mobile application is a central unit that receives all the measurements from

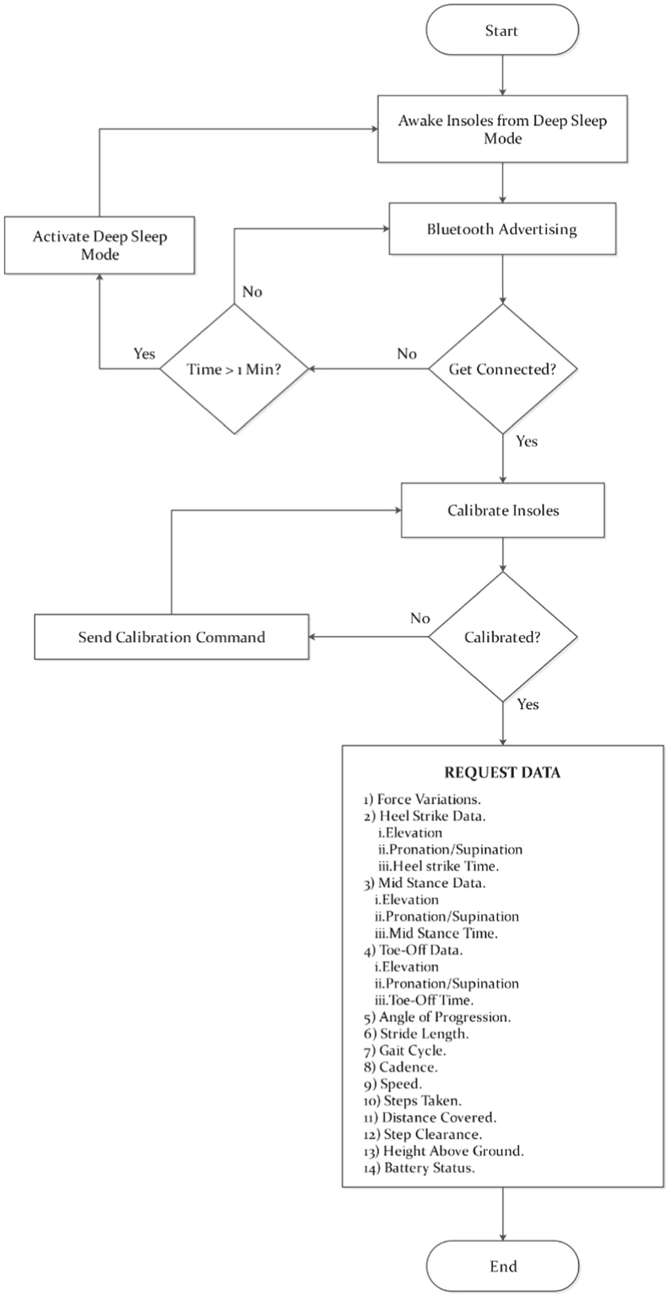

Fig. 7. Flow chart

the insoles and processes it. There are two types of data transmitted from insoles. One is real time data and the other is average data. The real time data provides gait parameters of each step immediately without any delay while the average data provides average gait parameters over a selected time span. End: Ending of a process.

4 Smartphone Mobile Application

LAAF smart insoles can offer precise acquisition of running biomechanics from both feet, while comfortably providing an unobtrusive way to monitor providing a full analysis of a person's performance and running technique. Furthermore, a smartphone Android and iOS LAAF App displays sensor data in real-time via Bluetooth low energy. LAAF smart insoles can be easily paired through Bluetooth to the mobile device. Once connected, one can see, in real-time, a heat map, distance, time, elevation, gait cycle, cadence, step length, foot strike, and pronation/supination displayed on the main home screen of the application. By simply tapping on each metric, the user is provided with additional insights and suggestions for performance adjustments. Another great feature is the Caregiver Appointment booking directly through the application. Caregivers and Users can have a live session by having the user wear an insole and record the real time values at the time of appointment for a defined period of time. Data collection by these appointments can be very insightful, as it can help the caregiver determine the prescription orthotics and optimal exercises. The LAAF Store, also located in the application, makes it easy to find the correct pair of high-quality insoles and other items at reasonable prices.

5 Discussion

In this proof-of-concept study, we used force sensitive resistors to measure pressure denoted by a colored heat map, a barometer, and a 6-axis IMU to calculate gait parameters like angle of elevation, pronation/supination, cadence and height above the ground. LAAF insoles are capable of calculating the important parameters for dynamic postures during various activities, as required by caregivers.

The mobile app can monitor pressure heat maps, and complete analysis of cadence, pronation, supination, heel-toe walkers, acceleration and stoppage time, balance and pressure on each foot with change of direction as compared to baseline and normative data. If any of these parameters exceed the defined range, the application provides patients warnings to make changes confirmed by caregivers. Consequently, this device by providing real-time foot monitoring and deep learning algorithmic analysis, empowers users for comprehensive management to reduce pain, prevent further injuries and maintain physical activity levels. Internal validation showed the accurate performance of pressure sensors to recognize the maximum pressures on the foot for all participants with IMU transmitted metrics to the mobile app in real time with defined timed reports.

With the LAAF insoles and mobile app, active users should see a reduction in their pain levels. In-App interaction between caregivers and users will assist caregivers to remotely access reports and assess progress over time. Those suffering from heel pain, plantar fasciitis, bunions, or hammertoes can feel relief with the comfort of the insole, while also working towards a proactive solution that addresses the underlying problems. Users recovering from previous injuries can use the LAAF app to monitor their progress in rehabilitation. This level of integration between collected data and real-time feedback allows the user to make adjustments with minimal effort. LAAF insoles provide a comprehensive solution to the root causes of pain.

6 Limitation and Future Studies

One of the limitations of our study is the high cost of skill and expertise needed for the accurate performance of the sensors, validity of data, and accuracy. Several iterations of the circuitry and materials were made. Other studies also faced this limitation so that prices of smart insoles are several times higher than regular insoles. Our study is a proof of concept and further studies are needed with larger sample sizes. Studies should be conducted to evaluate the usability of the system with user experience and caregiver feedback to determine the effectiveness of this system for improving self-management behaviors, decrease in pain, and increase in physical activity.

7 Conclusion

We developed an IoT smart insole with a mobile application to monitor and manage chronic pain. We evaluated the performance of the sensors and inertial measurement units and showed accurate performance of the smart insoles. Improper gait is an underlying issue which affects the kinetic chain of movement within the body. By neglecting to address the root causes of pain, people have often relied on reactive methods which address symptoms only. With LAAF insoles, users can monitor previously unobservable gait cycle data and manage the root causes of their pain. This can assist users currently in pain or those recovering from injury. Furthermore, the LAAF prototype shows that data collection, analysis, and in-app interaction with caregivers is possible.

Whether it starts from an injury or from overuse and lack of support, pain can lead to reduced physical activity and over-reliance on pain medication. LAAF guides users through their healthcare journeys as they learn more about their underlying cause of pain and find experienced caregivers to assist them. The unique approach of recommending solutions and providing a central repository for pain management allows users to find the best solutions with minimal time spent on irrelevant and imprecise research. Our services are designed to help customers better understand their own bodies. We want to empower people to find the support they need every day.

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Conflict of Interest. Authors declare that there are no conflicts of interests.

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Cognitive Neuroscience, Health Care and Artificial Intelligence (AI) Systems

Sense of Agency in Human-Machine Interaction

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Abstract. Although being in control is an important aspect of human-machine interaction, little is known about the combined effect of automation and mental workload on the sense of agency. In this study, participants were asked to reproduce the time interval between a keypress and an acoustic tone presented with different time delays (1250 to 2250 ms). Automation had three levels from the human being in complete control, an intermediate condition, to the machine being fully automatic. Mental workload was manipulated with a secondary memory task with two levels. Results showed a gradual loss of sense of agency with increasing automation intervention. Mental workload was found to affect only the intermediate automation condition. Further, we found an Intentional Binding effect for delays longer than 1750 ms in this intermediate condition. These findings demonstrate the existence of a residual sense of agency, which has important implications for the future design of hybrid, semi-autonomous systems.

Keywords: Sense of agency · Automation human-machine interaction · Mental workload · Time delay

1 Introduction

Over the past decade, the number of circumstances in which humans delegate actions to technology has massively increased. One of the consequences of this loss of action is the reduction of the individual sense of control, called 'Sense of Agency'. Haggard and Chambon [1] defined sense of agency as "the experience of controlling one's own actions, and, through them, events in the outside world". In other words, we experience sense of agency when we perform an action whose consequences are known [1–3]. The main effect of experiencing sense of agency is the well-known Intentional Binding Effect [4, 5] which refers to the compression of the time interval between a voluntary action and its effects. When the individual experiences sense of agency, actions and effects are bound together so that the individual's perception of the time between the two events is shorter than reality.

The role of sense of agency in human-machine interaction has been investigated by Berberian [6] who showed a decrease in agency with an increase in automation during an aircraft supervision task carried out in a flight simulator. Studies have also indicated that driving support decreases the driver's sense of agency [7, 8]. Work on sense of agency has so far focused on manipulating the degrees of human and machine contribution to a

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task [6, 9–11]. To our knowledge, no specific study has yet investigated the combined role of automation and mental workload on the sense of agency. Mental workload is a key aspect in human-machine interactions. Although introducing automation has been thought to relieve and simplify the human's task, it can produce fluctuations in the load on the human cognitive system [12, 13]. Those situations vary from the user carrying out other tasks in parallel, to lowering their attention level due to boredom, resulting in a disruption of their performance [14, 15]. One of the main consequences is a phenomenon called Out-Of-The-Loop (OOTL) performance [16] where the human is unable to take over control in the event of automation failure.

There is evidence of mental workload affecting the individual's sense of agency. For example, Hon et al. [17] reported reduced agency under high mental workload. This evidence was further investigated by Howard et al. [18] who looked for the intentional binding effect under two levels of mental workload. They demonstrated that mental workload does affect sense of agency when the task is carried out solely by the individual. In contrast, when the task is performed by a computer, the individual's sense of agency is not affected by any changes in mental workload.

The present study aimed to investigate sense of agency, as an indicator of user control, under different degrees of autonomy and mental workload. A similar experimental approach to Howard et al. [18] was used, but with a third intermediate condition. In our study, participants estimated the time interval between a) their action and a subsequent sound, b) their action when warned by the computer and the subsequent sound, and c) the computer action and the subsequent sound. We hypothesized that sense of agency would gradually reduce as computer intervention increased. Further, it was expected that the mental effort involved in task performance would reduce sense of agency, but only when the participants were physically triggering the action. When the computer triggered the action, we expected to see no effect of workload.

2 Method

2.1 Participants

One hundred and eighty individuals (83 female, 93 male, 4 non-binary), mean age = 20.53 years, SD = 2.00 years, participated in the study. They were recruited through the University students' mailing list. The University Research Ethics Committee approved the study.

2.2 Design

The experiment was counterbalanced in a three factor (automation: human decision, system warning and system decision) between-subject design and a two factor (workload: low or high) within-subject design. Automation was manipulated via the interval reproduction task, where a) participants would trigger a sound event by pressing a key at any time (human decision condition); b) participants would be alerted by the computer to press a key at any time to trigger a sound event (system warning condition); c) the computer would trigger the sound event (system decision condition). Workload was manipulated at the encoding stage. In the low workload condition, participants were presented with two letters to remember. In the High workload condition, participants were shown eight letters to remember. The order of presentation for the time delays (1250 ms to 2250 ms) was randomized and counterbalanced amongst blocks.

2.3 Materials and Procedure

The experiment was conducted online using Pavlovia open science repository (https://pavlovia.org) and visual stimuli were coded using Psychopy [19]. The experiment composed an encoding stage, the interval reproduction task, and a recall stage. Specifically, participants were asked to memorize letters at the beginning of each trial (encoding stage), to retain the letters while completing the interval reproduction task and finally they faced a recall where a probe letter was presented that they had to report as to whether the letter was previously present at the encoding stage [20]. In the interval reproduction task, participants were asked to reproduce the time interval between a keypress and following tone by pressing the spacebar twice, the first time to begin the estimation and the second to end it.

2.4 Data Analyses

A manipulation check of mental workload was carried out on the accuracy response that participants gave in the recall stage. This has been calculated as the number of times participants gave a correct response divided by the number of trials they completed. A logistic mixed-effects model was fitted to the data. This showed a significant main effect of workload ($\chi^2_{(1)} = 209.00, p < .001$); accuracy response was greater in the low mental workload (mean = 0.95, SD = 0.21) than the high mental workload condition (mean = 0.77, SD = 0.42). This was deemed satisfactory.

3 Results

Sense of agency was assessed by testing the effect of automation and workload on the Estimation Error. This has been calculated as the interval reproduced by the participants minus the actual time delay. A linear mixed effects model was fitted to the data with estimation error as the dependent variable, automation (human decision, system decision, system warning) and mental workload (high/low) as independent variables and participants ID as the random factor. Post hoc comparisons were assessed using t-tests and Bonferroni's correction was applied when needed.

A significant main effect of automation was found (F(2,178) = 6.19, $p = .002$). Estimation error was smaller in the human decision condition than the others (−28.67 ms, SD = 387.67, $p_s < .001$). Moreover, the system warning condition (mean = 30.92 ms, SD = 413.22) had a lower estimation error than the system decision condition (mean = 83.79 ms, SD = 366.83, $p = .004$).

The main effect for mental workload was not significant ($p > .050$). However, a significant two-way interaction between automation and mental workload was found, (F(2,3161) = 3.84, $p = .021$). Post hoc comparisons showed that estimation error was smaller in the low mental workload condition (mean = 1.80 ms, SD = 361.09) than the high mental workload condition (mean = 60.55 ms, SD = 458.68) for the system warning condition only (p = .011). This is shown in Fig. 1.

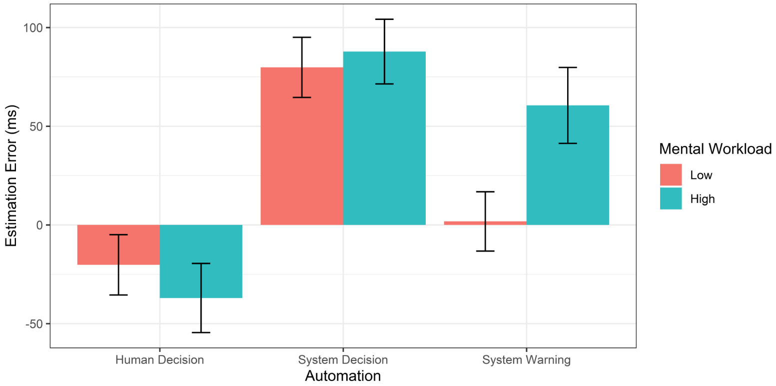

Fig. 1. Participants' estimation error for each automation and mental workload condition. Bars indicate the standard error of the mean.

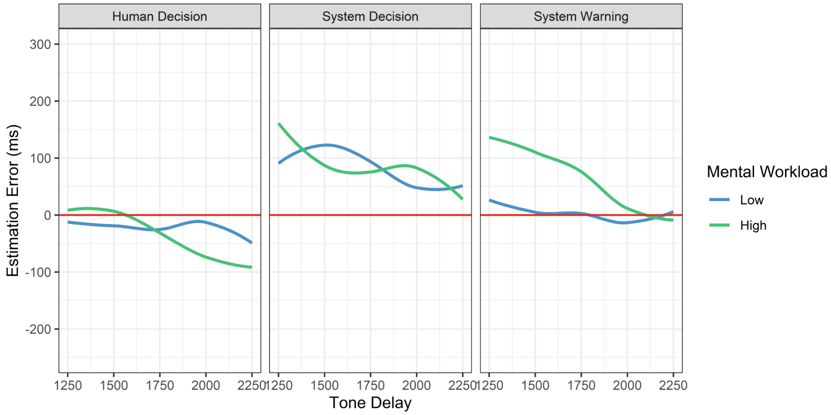

Fig. 2. Estimation error for each automation, mental workload and time delay condition.

The role of time delay in influencing estimation error was also investigated. For each automation condition, a mixed-effects model was fitted to the data, with estimation error as the dependent variable, workload (high and low) and tone delays as independent variables, and participant ID as a random factor. The results are shown in Fig. 2. For the system warning condition, the model showed a significant main effect of mental workload (F(1,1086) = 7.65, p = .005), which confirmed previous analysis with smaller error for the low mental workload condition. The tone delay was also found to significantly influence participants' estimation error (F(4,1086) = 2.59, p = .035). Post hoc comparisons showed a significantly smaller estimation error for tone delays longer than

2000 ms (p_s > .050). An Intentional Binding effect was found for low mental workload in the system warning condition for time delays longer than 1750 ms.

4 Discussion

This study investigated how the combination of automation and mental workload can affect the human sense of agency. The main hypotheses were that both automation and mental workload would degrade human sense of agency. Experimental results on the interval estimation task showed that automation affects the sense of agency and participants' estimation error increased with the reduction of their intervention. Therefore, automation seems to play a key role in the user's control perception, for which even a minimal 'intrusion' to their decisional process reduces their sense of agency. This is in line with previous literature [6–8].

Participants' estimation error did not change with the increase in mental workload. However, a significant two-way interaction between automation and mental workload was found. In the system decision condition, no effect for the mental workload was found. This mirrored the results of Howard et al. [18]. As no human action was involved in the task and no control was by the individual, mental workload did not play any role. No effect for mental workload was found in the human decision condition. This result differs from previous research [17, 18] that showed a greater sense of agency for low mental workloads in the condition of human decision. However, in previous experiments, shorter time delays have been used which may have led to this new finding here. As previous research indicated, a decrease of time estimation with the increase of time delays [21, 22] makes it plausible to assume that the lack of effect for the mental workload in the human decision condition was due to the so-called 'pacemaker effect' [23]. In other words, the individual has an 'internal clock' that is used when a causal link between the individual's action and the effect is established. This clock runs at a lower rate, so that the longer elapsed time between the action and the effect, the greater the bias between the perception of the time interval and the actual elapsed time. As this distance increases for longer time delays, it is possible it would reduce the difference between the two mental workloads.

Finally, mental workload was shown to influence the sense of agency in the system warning condition. Estimation error in this condition was higher than in the human decision condition and also higher still with a high mental workload. An explanation for this effect is that it could be linked to the depletion of cognitive resources. In the system warning condition, the participants were performing the keypress and it is plausible that the secondary memory task competed for resources with the primary task, further reducing the participants' sense of agency. These results confirm that automation and mental workload are related to each other and need to be investigated as complementary aspects of the same phenomenon. This also confirmed our hypothesis on the presence of residual sense of agency in a hybrid human-machine system, thus showing it would be possible to develop a shared human-machine control experience.

The time delay did not have any effects on the system decision and the human decision conditions. However, sense of agency increased in the system warning condition with the lengthening of the time delay. Moreover, intentional binding has been found for time delays longer than 2000 ms. Estimation error was always relatively small, and even negative for delays longer than 1750 ms in the low workload condition. For the high workload condition, a constant decrease of estimation error can be observed. This confirms the presence of some residual agency, possibly because participants were still in charge or triggering the sound. This, in turn, could depend on the temporal contiguity of the warning and the sound. A sound triggered 1250 ms after the key press could be temporally closer to the warning than a sound triggered after 2250 ms and, therefore, perceived as a consequence of the computer warning rather than the participants' action itself. The opposite would be for a longer delay, where the sound could be temporally closer to the individuals' intentional action.

Anticipating the machine intervention early enough to make the individual's compliance fall into the intentionality area would be an important step forward. This could have important and beneficial consequences, as sense of agency has been shown to be linked to greater attention, improved motivation, and attribution of responsibility [24–27].

5 Conclusion

The paper strengthens the evidence that sense of agency can be used as a tool to measure human involvement in a human-machine interaction task. Results have shown that automation and mental workload are interconnected in playing a key role in influencing the sense of agency whilst at the same time demonstrating the existence of a residual sense of agency in a hybrid environment. This finding opens up the possibility of integrating operator and machine actions while maintaining the individual's perceived control.

These results indicate that sense of agency needs to be considered in the design of hybrid systems. Specifically, a precise time window for the user intervention should be optimised; in this work we found that the system should provide information or instructions around 2 s before the user intervention. This would allow the user to maintain control over the task, thus improving the quality of the performance.

Further, mental workload needs to be carefully considered in a hybrid system when instructions need to be completed sooner than the optimal, in the case investigated 2 s, time window. In conditions in which the user intervention needs to be immediate, mental workload should be light to allow the user to be in control.

Finally, in a fully automated system, the user would not be in control of the system, and the inclusion of sense of agency in the design would not deliver any improvement. However, each system is different and managing what level of user interaction is required in the system should be a topic for future research.

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The Differences in Information Transmission Efficiency - A Comparison of Analog and Digital Media

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Abstract. In Japan, many people are still not familiar with reading documents digitally, although digital books have been widely promoted recently. To disclose the obstacles preventing digital reading, a fundamental experiment investigating the difference in information-transmission efficiency between analog and digital media was performed. In this investigation, the participants were asked to read documents in two different forms, in a printed form (analog media) and a displayed form (digital media). In addition to the analog and digital comparison, the experiment analyzed another aspect: the differences among young, middle-aged, and senior generations. Herein, the results of the investigation and the implications of the experiment results were discussed.

Keywords: Reading documents · Digital publication · Comparison between analog and digital media · Differences in reading behaviors among young, middle, and senior generations

1 Introduction

Digital technologies rule the current society. However, digital books are not as popular as expected in Japan because of the conservative behavior of the Japanese population; they prefer reading paper books rather than digital books. Moreover, it has not been disclosed whether there are any scientific differences in understanding the content of documents between the two types of reading: to read the content in printed paper or to read the content displayed on the computer monitor. Although it is explained that the readers see the content in a printed copy through the reflected light, and the document displayed on a computer monitor through the transmitted light [1], it is not clear how this difference affects the efficiency of understanding the content. To clarify if there is a difference in understanding through paper and digital media, several materials in the different media were read by the participants.

Regarding reading behavior, one more aspect is essential to this investigation; that is, reading experiences are highly dependent on the readers' life experience and their

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maturities. Therefore, the participants were separated into three categories: younger, middle-aged, and seniors. Additionally, the experiment had several interests in reading behaviors. Hence, the participants were requested to wear the eye-tracker to record their gazes' movements while reading a document. One of the research questions was whether we could confirm the difference in the gaze movements for reading a paper displayed in analog media and digital media.

The rest of the study is structured as follows. In Sect. 2, related work is described. In Sect. 3, an overview of the experiment is presented, and Sect. 4 shows the experiment results. Finally, conclusions and future work close the manuscript in Sect. 5.

2 Related Work

Similar studies have been reported on digital reading. This section introduces several studies in this field and describes the similarities and differences between this investigation and previous studies.

Warlen *et al.* [2] studied the effects of screen size on the emotions in digital reading. Three randomly assigned devices with different screen sizes (laptop, tablet, and smartphone) were provided for the experiment. The subjective evaluation and face recognition software were adopted, and it was concluded that the small screens were unfavorable in digital reading.

Similar research has been reported by Al Ghamdi *et al.* [3, 4]. They also analyzed the impact of the mobile phone screen size on user comprehension of health information. Several parameters, including correctness, the effectiveness of completing tasks, content ease to read, clarity of information organization, and comprehension were measured. This approach is similar to the method developed in this study. However, there is a clear difference regarding the fact that they only focused on the screen size of digital devices. In contrast, our experiment compared digital and analog media, and the dimensions of the displayed documents (and paper sizes) were fixed.

Hsieh *et al.* [5] also conducted a study on the reading efficiency according to the mobile devices' screen size. They compared not only the devices which have different screen sizes but also paper media. An interesting point is that the reading speed in digital media was faster than that in paper media. This result is similar to the result obtained in our experiment.

Gómez *et al.* [6] considered that the eye-movements revealed the task performance while reading. They classified several patterns using the principal component analysis to support their hypothesis; the idea was impressive, and it would be possible to adopt in our research.

3 Experiment Methods

This section describes an overview of the experiment, which was performed from 8th Dec. 2020 to 11th Dec. 2020. Thirty-two subjects including twenty males and twelve females participated in the investigation.

The experiment was carried out following the procedures below:

1. Seven documents were prepared to be read in the investigation and were divided into three types: a) only characters, b) only figures, and c) mixture of characters and figures.
2. Participants were also divided into three categories: younger generation (students from Chuo University), adult generation (office staffs of TOPPAN FORMS CO., LTD., hereinafter, this is called "Toppan"), and seniors (retired persons).
3. Two groups were formed: the first only read documents printed on papers, and the second read the digital documents displayed on a computer monitor.
4. The subjects wore the eye-tracker throughout the experiment. The documents were shown for a short time until the issue indicated that the participants understood the papers' content.
5. The gaze movements were measured by the eye-tracker and recorded on the computer. Each time, after the participant read the document, the facilitator conducted a short interview to confirm the participant's understanding.
6. In this experiment, the participants were asked about their familiarity with reading documents, using information technology devices and services.

The experiments were performed at the laboratories of Toppan. Figure 1 shows the situation in which a participant wearing the eye-tracking system read the document displayed on the computer monitor.

Fig. 1. A subject of the experiment wearing the eye-tracker read a document displayed on the computer monitor. The person on the left recorded the gaze movement data, and the person on the right facilitated the experiment procedure.

Figure 2 illustrates an overview of the seven documents shown to the subjects. Within 1.5 h per experiment, not all participants could finish reading all copies.

It also indicates the area of interest (AOI) configured for each document. The AOI is determined to evaluate which part of the content attracted the readers; that is, the area where the gaze records were intensively focused is considered the most interesting area.

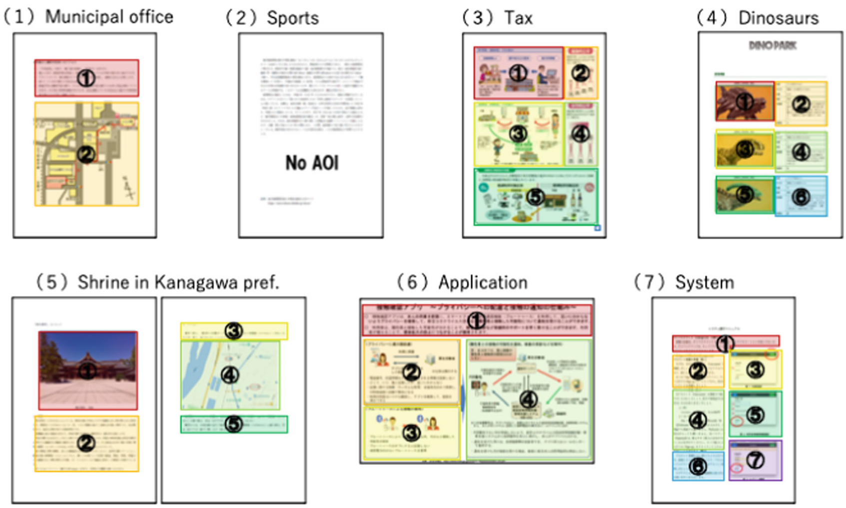

Fig. 2. Illustration of the seven documents presented to the participants in the experiment. The keywords shown above the thumbnails of each document are the titles. Each document, except “Sports”, has its AOI configured to analyze the readers’ most attractive part.

4 Experiment Results

As previously mentioned, a total of thirty-two subjects participated in the experiment. Twelve students from Chuo University joined it as the younger generation’s representatives, ten office staff from Toppan joined as the middle-aged participants, and ten persons from Silver human resource center joined as the senior participants, respectively.

4.1 Reading Speed and Levels of Understanding

The results of the experiment are shown in Figs. 3, 4, and 5.

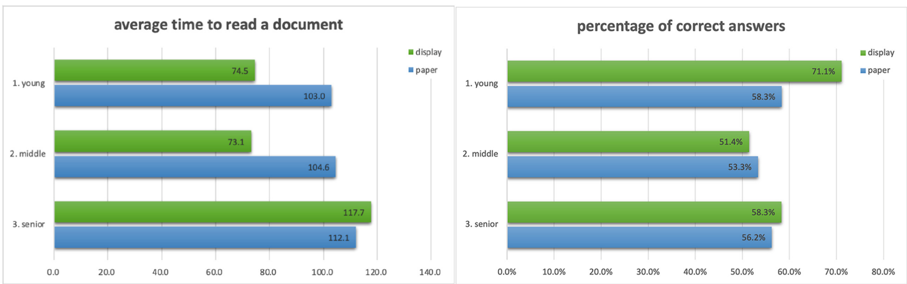

Fig. 3. Average time to read a document (left) and percentage of correct answers (right). The green and blue bars indicate groups A (digital) and B (analog), respectively.

The average time to read a document is shown in the left part of Fig. 3. It shows that the average times of group A (digital group), in which the subject read a document on the computer screen, are shorter than those of group B (analog group), in both young and middle-aged categories. The average correct answer rate is high for the younger generation of group A. Overall, the percentage of correct answers is high for young people, but the fact that some of the subjects were involved in question creation is undeniable.

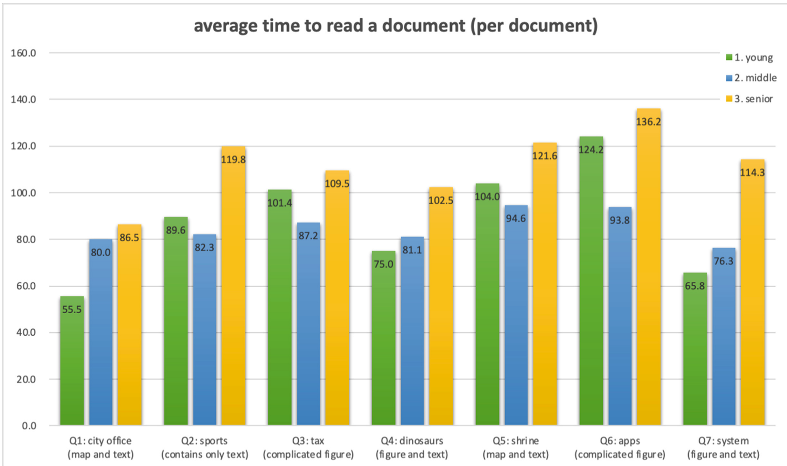

Fig. 4. Average times to read per document. In all papers, senior persons took a longer time to read it.

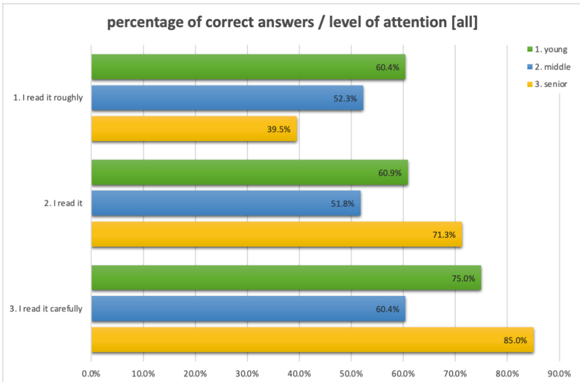

Fig. 5. Percentage of correct answers calculated per level of attention.

Figure 4 shows the average reading times, which are calculated using each document. It indicates that older adults need more time to read a document.

The participants were asked to indicate the attention level while reading the document, every time after they have read the document. The attention levels were divided into three categories: 1. I read it roughly, 2. I read it, and 3. I read it carefully. Figure 5 shows the percentage of correct answers calculated by the levels of attention. For all generations, the cases of carefully reading have a higher score of correct answers. Conversely, it would be considered a typical result for the senior generation's shallow score on roughly reading.

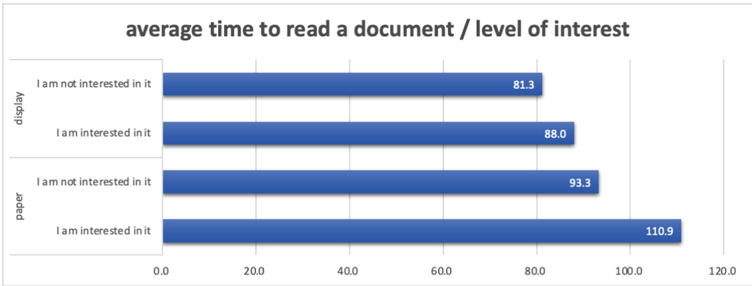

Fig. 6. Average time to read a document per level of interest.

Furthermore, the participants were also asked about the interest levels on the document. That is the question of whether the subject had an interest in the document or not. Figure 6 illustrates the result of the calculation. Regardless of the interest levels, the average time expended reading a document in a paper media took longer than that displayed on the computer screen.

4.2 Gaze Tracking Records

In the experiment, the gaze tracking record was collected. Based on the recorded data, the heatmap and dwell-time analyses were performed. Figures 7 and 8 show the examples of the heatmap and dwell-time analyses, respectively.

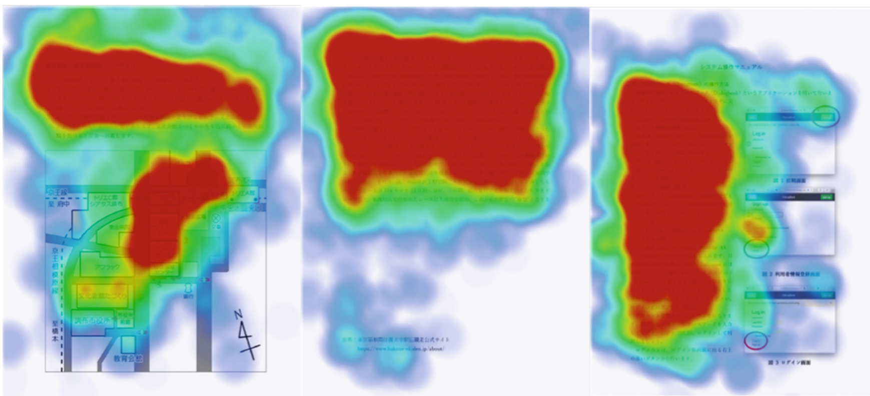

Fig. 7. Results of the heatmap analyses for the three documents: "Municipal office" (left), "Sports" (middle), and "System" (right), respectively. The most focused area is painted in red, and the color changes from orange, yellow, green, to blue as the focus decreases.

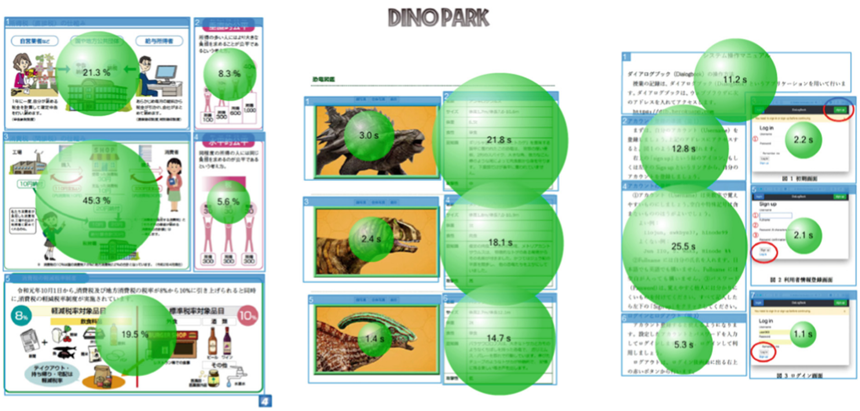

Fig. 8. Results of dwell-time analyses of the three documents: "Tax" (left), "Dinosaurs" (middle), and "System" (right), respectively. The dwell-time for each AOI is represented in a green balloon. The balloon size means the staying duration in the AOI.

According to these results, several findings were obtained. The heatmap and dwell-time balloons indicate that almost all participants intensively look at the text segment while reading the document. They did not focus on the figures, which means figures in the paper were used to transfer the supplemental information.

However, we could not find any apparent differences between the eye-tracking data of two groups: those who read the document in the digital media and those who read them in the analog media.

5 Conclusions and Future Work

Reading documents on computer monitors have been widely used in recent days. However, the efficiency of reading and understanding the contents using different media are not disclosed. In this research, a fundamental experiment was performed as the first step of the study.

Several findings on the difference between reading documents through paper media and digital media were described, disclosed by the experiment's results, which were based on the answers to a questionnaire and the records of the gaze movements.

The time to read the document and some responses to the questionnaire indicated that the elderly people preferred and were more familiar with the paper media compared to the digital display. Although it is considered obvious, the results can help planning some printing businesses focusing on the senior generations. Because the Japanese society is an aging society with a declining birth rate, it may be meaningful to consider a special printing business for elderly persons.

We expected that the experiment results would give us some scientific indications to determine the difference in reading documents' efficiency using different media. Because the responses to the questionnaire were subjective and qualitative, the gaze movements were relatively objective and quantitative. Unfortunately, the eye-tracking data results did not indicate any clear difference between reading documents in digital and analog forms. An in-depth investigation is needed to find some implications from the gaze tracking records.

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Using Virtual Reality in the Treatment of Social Anxiety Disorder: Technological Proposal

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Abstract. The treatments for anxiety that have proven efficacy are based on cognitive behavioral therapy, this time we will focus on systematic desensitization, which aims to expose the subject successively to the element that generates the maladaptive response, with this purpose a technological application is proposed for the treatment of this disorder from virtual reality. To accomplish this goal, an electronic helmet where different scenarios will be projected is going to be used. The person who is wearing it will face the distressing stimuli, allowing the treatment of his/her anxiety. With this application and device, it will be possible to safeguard the physical and psychic integrity of the subjects that demand this type of attention.

Keyword: Anxiety · Systematic desensitization · Virtual reality · Psychological therapy · Social anxiety disorder

1 Introduction

Social anxiety disorder, as every other anxiety disorder, refers to the fear, distress, and trying to avoid a determined stimulus. When a person presents social anxiety disorder, he/she feels that is being the target of negative judgments and laughs from the social interaction, and it will happen in many different contexts, for example, in the scholar environment when there is the need to be in front of other students, even when is eating or drinking in front of others. So, this explains why people presenting this disorder avoid any social event, or any place where they could feel they are not safe [1, 2].

People with this disorder worries for being judged by the others as an anxious person, weak, mental ill, dirty or disgusting, not forgetting the physical changes they could present, such as facial redness, trembling, stumbling, sweating, paused speech; these

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behaviors and thoughts make his/her life to be impaired, because of it, they tend to avoid even simple daily life activities, for example, buying something in the supermarket, or, asking for an address, at the school, it is possible to see that this student miss the day he/she was supposed to talk in front of the rest of the classroom or when there is teamwork that needs to be done because they rather avoid these situations [3].

Even when they have arranged to assist to an appointment or social event, just thinking about this experience could bring an irrational worrying and fear days or even weeks before this meeting, and, in the end, they rather miss it or, in the case they assist, they would feel very uncomfortable during the reunion, their thoughts will be directed to how everybody around is judging him/herself, even many hours after the reunion has finished. This same fear will interfere with every other daily activity, in the job place, for example, these people will show themselves as a shy and isolated, also they could talk with a very low tone of voice, showing difficulties to make friends, and finishing or losing a job because of social interaction [2].

One of the most important characteristics of people presenting this disorder is that they recognize the fear to be surrounded by people as excessive and irrational, although, the principal reason that stops them for asking help is the feeling of being embarrassed, preferring, like this, to avoid every social contact, and deciding to isolate themselves, which at the same time would trigger other disorders related to depression and stress [4].

2 Systematic Desensitization

Systematic desensitization (SD) is a behavioral-cognitive technique that helps in the treatment of anxiety and avoiding behaviors that appear as answers to stimuli that would generate distress in a person [5].

In the execution of this kind of treatment, the person must receive training based on the control of anxiety physiological reactions that will show when facing a determined stimulus. The success of this process is based on the autogenous or progressive relaxation which activates at the moment when the person presents an anxious response facing a stimulus [6].

Henceforth, through this relaxation training, a person could be close to the different stimuli that trigger physiological answers such as muscle tension and increased heart beating or respiratory rates. In this way, the individual would reduce these maladaptive responses and there would subsequently overcome his/her anxiety disorder, specifically the one it is being approached in this work, social anxiety [7].

In this treatment, the individual is exposed in a successively way to the stimulus that generates a negative answer. For example, in the social anxiety disorder, the person suffering it could show him or herself distress when talking in front of others, in this scenario, besides the therapist define the subjective units of distress (SUDs) that creates this situation, defining a baseline of working and as relaxation is incorporated, the individual must get closer to the distressing element, diminishing the SUDs, hence, facing its anxiety disorder [8].

3 Treatment Proposal Through Virtual Reality

As it was described above, a person who receives the psychological treatment based on the systematic desensitization will be exposed successively to the stimulus that triggers the negative response. It is important to address that this exposure could represent a risk to the person experiencing it, because of the physical responses that would appear, and, if something unexpected arises, it could bring negative consequences for the person exposed. Hence, interventions for anxiety based on virtual reality keeps the person exposed safe and away from the exposure risks [9, 10] (see Fig. 1).

Fig. 1. Technological proposal of treatment for social anxiety disorder with virtual reality

Therefore, our treatment proposal will be based on a technological application that will keep the scenario of exposure safe for the person who is receiving the treatment for anxiety disorder. This represents a significant contribution for the present psychological treatments, in the case of social anxiety, the individual who is being treated, will not present the same amount of distress when talking in front of people, decreasing like this the negative impact that not being in treatment would bring in the familiar, social, individual and any other contexts where the person develops, for example, presenting low self-steam, shame, or trouble when making teamwork.

In this sense, the application to develop must have the following elements:

1. A controlled environment where the person would be able to receive his/her treatment for social anxiety disorder.
2. Interaction with the application through a virtual reality helmet.
3. Physiological response markers, that will allow monitoring heart beating rates, respiratory frequency, motor, thermal, and any other responses that would arise when a person suffers social anxiety disorder is exposed to a distressing stimulus.
4. Scores obtained, these punctuations will allow the person treated and to the therapist to have feedback about the achievements reached thanks to the treatment.
5. Different levels of social anxiety exposure, from the resolution of social difficulties in a story, until being prepared for the real social contact (Fig. 2).

Fig. 2. Example of a scenario where a person presenting social anxiety disorder is exposed to a designated level of social interaction

4 Previous Research of Virtual Reality Used for Anxiety Disorders

Previous research has described the benefits of the intervention through virtual reality to treat anxiety disorders. Table 1 shows a revision of studies that have approached this thematic and will be used to build-up the technological application of interest in this work.

Table 1. Previous research

Title	Authors	Intervention protocol	Findings
Virtual reality exposure therapy for social anxiety disorder: a randomized controlled trial	Anderson et al. [11]	Virtual reality scenarios for a conference room, virtual class and a virtual auditorium	The realized exposure contributed significatively to the treatment of social anxiety disorder and its effects were seen one year after the intervention treatment
A virtual reality system for the treatment of stress-related disorders: a preliminary analysis of efficacy compared to a standard cognitive behavioral program	Baños et al. [12]	Virtual world with scenarios that represent nature with the manipulation of objects, sounds, images, colors, lights, and texts	There were found improvements in relaxation intensity, depression, and social interaction

(*continued*)

Table 1. (*continued*)

Title	Authors	Intervention protocol	Findings
Virtual reality exposure training for musicians: its effect on performance anxiety and quality	Bissonnette et al. [13]	A virtual situation where musicians play their instruments in front of a variety of auditoriums with different levels of presence of public and judges	It was reported a decrease in the anxiety level for the musicians when performing
Virtual reality compared with in vivo exposure in the treatment of social anxiety disorder: a three-arm randomised controlled trial	Bouchard et al. [14]	A virtual scenario where the person exposed is in front of a classroom and social interacting in daily life situations	Virtual treatment resulted in being more effective than exposure in vivo. Participants that were exposed to virtual reality evidenced lower levels of anxiety
Efficacy of virtual reality exposure therapy for the treatment of dental phobia in adults: a parallel group randomized controlled trial	Gujjar et al. [15]	Situation where the dentist realizes different procedures such as surgeries, dental cleaning, and tooth removal to the patient	The exposure to virtual reality decreased the level of anxiety in the dental professional attention

5 Conclusions

Psychological treatment for social anxiety disorder is a clinical procedure that stills in development. One of the most interesting proposals to approach it is the systematic desensitization therapy, it consists in the successive exposure of the patient to the distressing stimulus, through the process relaxation it is found the decreasing of the negative physiological responses.

Is important to mention that this procedure gives important advances to the patient, although, it is not secure at all when comes to control the variables that could generate any risk for the patient, because, if something unexpected appears, would be risky and could bring some negative outcomes in the person's life.

As a contribution to this research line, from the usage of the technology, it is proposed to develop an application that allows to control and overcome the risks that the patient would face when being treated. Hence, in this work, it is proposed the usage of an application of virtual reality where it would be possible to apply the systematic desensitization in patients presenting social anxiety disorder while being exposed to the trigger stimulus.

The content of the technological develop proposed sustains that there must be a controlled environment and with contextual validity for the individual presenting social anxiety disorder; the interaction with the application must be with the usage of a virtual reality helmet, with physiological markers of responses, scores for feedback for the patients and the clinician, also it must contain different levels of exposure to social interaction, allowing the person to improve the conditions of their social phobia.

The next step that will be realized in this research is the technological prototype design and its application through a quasi-experimental study in people that present social anxiety disorder.

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Product Design for Yangliuqing Woodblock New Year Paintings Based on Eye Movement Experiment

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Abstract. The Yangliuqing woodblock New Year painting in Tianjin is one of the four major New Year paintings [The four major New Year paintings include woodblock New Year paintings in Mianzhu, Yangliuqing in Tianjin, Yangjiabu in Shandong, and Taohuawu in Jiangsu. Woodblock New Year paintings are color-overprinted woodblock New Year decorations that change every year. People put them indoors to wish good luck in the New Year.] in China and has been included in the protection list of "Intangible Cultural Heritage". However, most of products about Yangliuqing only contain the visual elements directly and are designed for the purpose of decoration. In addition, the traditional paintings can no long reach the modern aesthetic standard. In order to solve this problem, the research aims at collecting and analyzing the eye movement data of products about Yangliuqing. Then, with factor analysis method, the visual image elements of the products were achieved by calculation and filter, finally actualizing the improvement and design for products after element deduction and recombination. The scheme effectively improved the problems existing in the actual design and application of traditional prints, which has certain reference significance for the extraction of visual images and innovative applications in traditional Chinese painting.

Keywords: Yangliuqing woodblock New Year paintings · Product design · Eye movement experiment · Factor analysis method

1 Introduction

The Yangliuqing woodblock New Year paintings[1] in Tianjin is the product of not only the material cultural form from the explicit aspect, but the spiritual belief from the implicit aspect. As the treasure of Chinese traditional folk culture, Yangliuqing painting is confronted with numerous difficulties in inheritance. Due to the development of New Year decoration art, the practical value of Yangliuqing has gradually declined, but it still has great artistic research value [1]. At present, there exists a large number of products

[1] The Yangliuqing woodblock New Year pictures were produced in the Ming Dynasty of China, centered on Yangliuqing Town, Tianjin, China.

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about Yangliuqing paintings in the market. However, most of them only contain the visual elements directly from New Year paintings. In addition, as the social values and tastes changed, the traditional paintings on products can no long reach the modern aesthetic standard to certain extent. There have been no efficient solutions to improve, nor reliable method to solve the problems existing in the actual design and application of traditional prints.

2 Current Status and Research on Products About Yangliuqing Paintings

Yangliuqing woodblock New Year paintings have formed a unique form of folk art [2]. At present, Yangliuqing paintings have been widely used in product design. After data gathering and research on online or offline shops, this article investigates 113 products on sale in the online store. Among these products, 60.2% use Yangliuqing patterns directly without redesigning. The main creative point is focused on the pattern of products, as shown in Fig. 1.

Fig. 1. Yangliuqing cultural and creative products (Pictures from Internet)

The research conducted a survey on online stores and found that 80 kinds adopt the patterns of Yangliuqing paintings among 113 kinds.[3]. The pattern of "More than a Year in a Row" (Fig. 2.A) has been used in 35 kinds of products. Besides, the paintings "Live to be a hundred" (Fig. 2.B), "Beauty holding baby" (Fig. 2.C), "Beauty Sitting alone" (Fig. 2.D) are also broadcast used, becoming the mainstream patterns in product design.

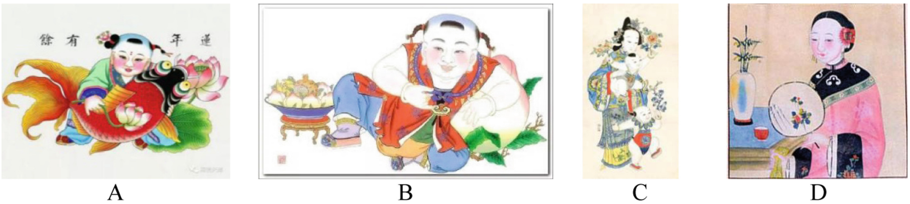


Fig. 2. A. More than a year in a row; B. Live to be a hundred; C. Beauty holding baby; D. Beauty sitting alone

Aiming at the problem of the lack of creativity and modern aesthetics in the product design of Yangliuqing, we select the new year painting "More than a year in a row" as a typical representative. It was selected as the experimental sample together with the most popular product type — Notebook (Fig. 3).

Fig. 3. Notebook design with Yangliuqing painting

3 Research Process

This paper focuses on eye movement analysis and factor analysis method to filter areas of interest with high visual attention. Then we combine the designer's knowledge of culture to extract characteristic elements and establish a design map [4]. The specific research framework is shown in the Fig. 4.

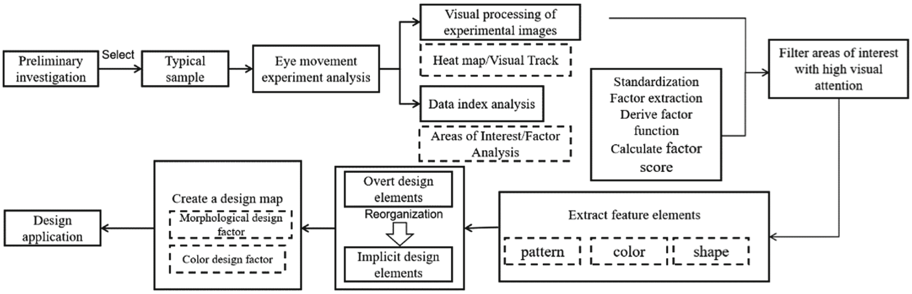


Fig. 4. Research framework

3.1 Eye Movement Experiment

(1) Subject and Experimental materials
It is intended to select 30 subjects who experience in product design aged between 18 and 40, and all subjects who have never seen experimental samples before as test subjects. A case image sample of Yangliuqing products is selected. In order to avoid the influence of its color, there is another image sample that has been grayscale processed. At the same time, to prevent visual retention from affecting the experiment, an image with a pure gray background is inserted. They are all 1890px * 1417 px, 300 dpi. See Fig. 3.

(2) Experiment process

The eye movement tracking experiment is conducted in a laboratory with stable light and good sound insulation [5]. The experimental process is shown in the Fig. 5.

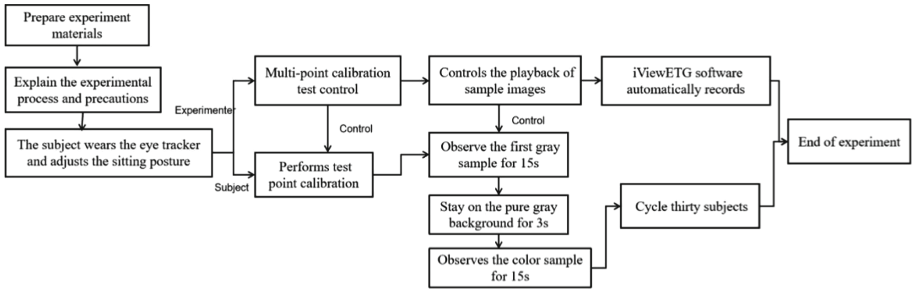


Fig. 5. The experimental process

3.2 Experimental Data Analysis

The experimental data is processed and analyzed by BeGaze data analysis software, mainly from the three aspects of Area of interest, Visual Track and Heat Map. It was found that the eye movements of three subjects flickered. Therefore, only 27 samples of subjects were analyzed and processed in this experiment.

(1) Analysis of Area of interest, Visual Track and Heat Map
The visual track reflects the browsing order in which the participant observes the sample, and the size of each moving point represents the length of fixation time.[4] In Fig. 6 (1), the subject first looked at the baby portrait. The visual trajectory of the gray scale sample Fig. 6 (2) is similar to that of sample 1. The heat map reflects the participants' attention to different areas of the sample. [4]. The results show that regardless of whether it is a color sample or a grayscale sample, the subjects' main focus areas are still baby portraits, fish heads. As shown in Fig. 6 (3) and (4). Area of interest (AOI) is the division of experimental samples into different areas. As shown in Fig. 6 (5), the image sample was divided into 9 regions to quantitatively analyze the attention degree of subjects in each region.

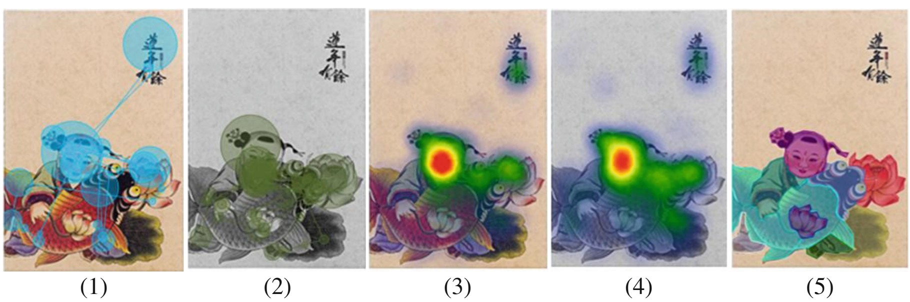


Fig. 6. 1. Visual track of sample 1; 2. Visual track of grayscale sample; 3. Heat map; 4. Heat map of grayscale sample; 5. Region of interest division of sample 1.

(2) Factor analysis method

This experiment uses the Metrics statistics function module to derive the eye movement index data. However, too many indicators are difficult to reflect the attractiveness. Factor analysis method is used to reduce the dimensionality of indicator variables. [0]Steps are as follows:

a. Standardized processing to eliminate data errors caused by different index units and different evaluation standards; The formula is as follows:

$$z_{ij} = \left(x_{ij} - x_j / \sigma_j\right)$$

b. Spherical test. Among them, the KMO value is greater than 0.6, and the P value in Bartlett's test is less than 0.001, so factor analysis can be performed.
c. Then, we use regression method to analyze the weight of factors, and use "component score coefficient matrix" (Table 3.3) to establish the relationship equation between factors and research items.
d. Use SPSS to extract the factors. The factor analysis extracts a total of 2 factors. The factor score function can be written according to the calculation results:

Degree of Visual Attention = −0.157*Entry Time Average + 0.248* Revisitors Count + 0.139* Revisits Total-0.039* First Visual Intake Participant Count + 0.100*Glance Duration Total + 0.216* First Visual Intake Duration Total + 0.098* Dwell Time Total + 0.170*Glances Count Total.

Degree of Content Richness = −0.626* Entry Time Total + 0.355* First Visual Intake Participant Count −0.185*Glance Duration Total + 0.116* Dwell Time Total (Table 1).

Table 1. Component score coefficient matrix

Name	Factors	
	Factor 1	Factor 2
Entry time total [ms]	0.235	−0.626
Entry time average [ms]	−0.157	0.017
Revisitors count	0.248	−0.229
Revisits total	0.139	0.027
First visual intake participant count	−0.039	0.355
Glance duration total [ms]	0.100	0.112
First visual intake duration total [ms]	0.216	−0.185
Dwell time total [ms]	0.098	0.116
Glances count total	0.170	−0.038

(3) Analysis Conclusion

According to the above formula, the comprehensive scores of 9 regions of interest are calculated, and the results are arranged into scatter plot 3.8. It can be concluded that AOI1, AOI5, AOI7, AOI8, AOI9 have the highest degree of visual attention and content richness (Fig. 7).

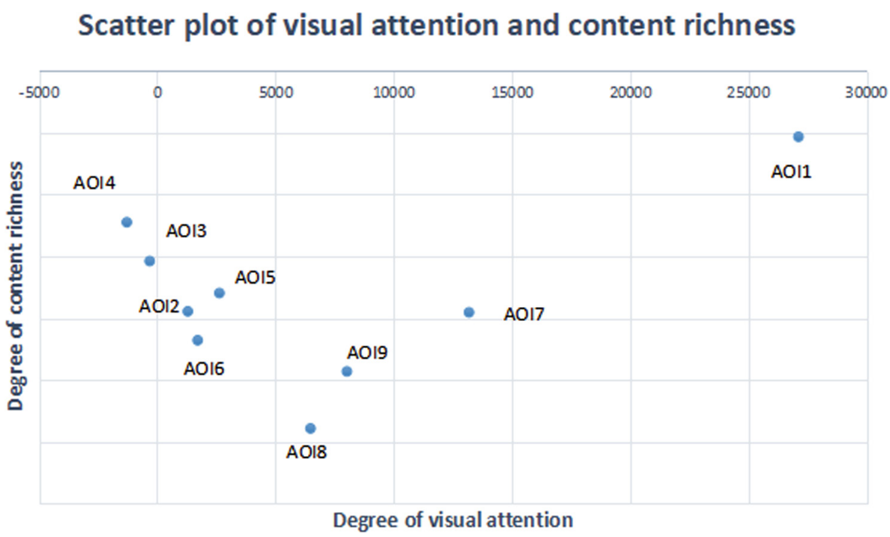


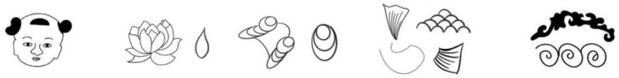
Fig. 7. Scatter plot of visual attention and content richness

3.3 Experiment Findings

According to the above data analysis, the visual image elements in five key areas of interest were extracted from two aspects of patterns and color.

After extraction, the element illustration was established and applied to product redesign. In terms of color, the original color saturation is very high. It brings heavier mental pressure to modern people who are living in a quick-spaced and high-loaded life. Therefore, it is necessary to reduce the saturation of extracted colors to approach current tastes. The experimental findings are shown in Table 2.

Table 2. Extraction of design elements of new year picture "More than a year in a row""

Areas of interest	AOI1 baby portrait	AOI8 lotus 1	AOI9 fish head	AOI7 fish body	AOI5 body
Extract objects					
Morphological extraction					
Color extraction	R:126 G:89 B:115; R:222 G:196 B:159; R:245 G:181 B:165; R:16 G:13 B:24	R:209 G:68 B:62; R:217 G:158 B:41	R:16 G:13 B:24; R:238 G:201 B:28	R:226 G:19 B:24; R:233 G:254 B:0	R:179 G:212 B:101; R:97 G:26 B:67; R:255 G:25 B:0; R:256 G:205 B:137
Improved colors	R:244 G:219 B:202; R:234 G:150 B:159	R:191 G:77 B:67	R:247 G:201 B:141; R:176 G:191 B:132	R:16 G:13 B:24	R:157 G:104 B:115

3.4 Improvement and Design of Yangliuqing Woodblock New Year Paintings

Based on the element extracted from the painting, the areas of interest were selected and adapted. In AOI1, the baby's face and hairstyle elements were retained and the facial expression was adapted. Secondly, the original complicated fish body and clothes were simplified in shape and color. To maintain the overall unity, the color of lotus leaves was adjusted into the same with clothes. Finally, to insert more fun and humor into the pattern and enrich the composition, a slogan of "I'm tired" was added, which corresponded to the facial expression. This was applied to the product design of the notebook, as shown in Fig. 8 (Fig. 9).

Fig. 8. Improved design of Yangliuqing cultural and creative products

3.5 Design and Analysis of Confirmatory Experiment

In order to verify the effectiveness of the optimized design, the research uses qualitative analysis and quantitative analysis to evaluate it. Quantitative analysis is based on the physiological indicators of eye movement experiments. The results show that the optimized design is higher than the traditional design in terms of visual attention, regardless of whether it is gray or colorful samples. As shown is Fig. 10.

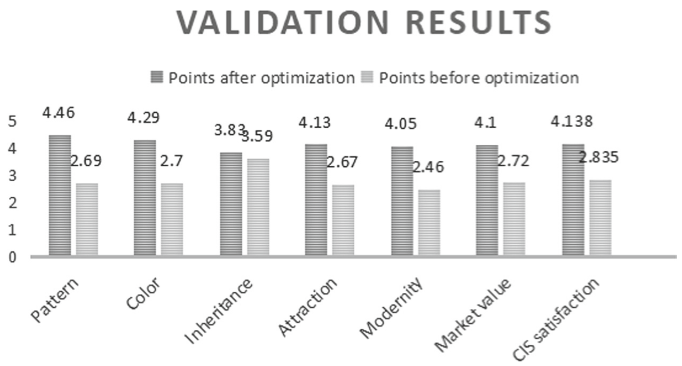


Fig. 9. Validation results

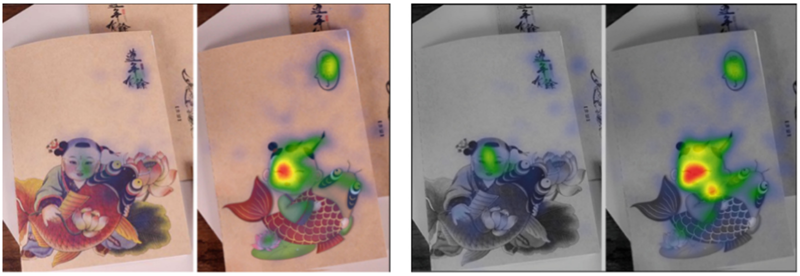


Fig. 10. Validation experiment heat map (color sample). Validation experiment heat map (gray sample)

The qualitative verification is based on questionnaire surveys (including 202 subjects). The result show that the scores of the various evaluation indicators of the optimized design have been improved. The CIS of the optimized design is 4.138, and the traditional design is 2.835. Therefore, both from a qualitative and quantitative perspective, the research proved the effectiveness of the optimized design.

4 Conclusion

The research puts forward eye movement experiment and factor analysis method to improve design of cultural and creative products of Yangliuqing. Through people's attention to the color and form of Yangliuqing, we excavate and extract design elements and then reinterpret and combine them. This helps to improve the problems existing in the actual design and application of traditional prints, which has certain reference significance for the extraction of visual images and innovative applications in traditional Chinese painting.

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Human-Computer Interaction (HCI) Approach for the Optimal Generation and Selection of Batches Destination Options in Steel Making Factories

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Abstract. The objectives of the destination options generation of the semi-products batches coming from the continuous casting installations for the production of finished steel profiles in lamination workshops are close to the minimum of the excess of mechanical properties respecting its normed values in the steel industry. The estimation of mechanical properties of the batches starting from its chemical composition and traverse surface of the billets and finished profiles is done by radial based neural networks, starting from the available mechanical properties data obtained from the quality control of the workshops. The systemic analysis of the production function in steel factories allows to formulate the conceptual optimization model, that breaks down in sub-models of the batches destination options generation, as a discrete stochastic optimization and the selection of the batches to be to satisfy the sales demand sub-tasks. Solutions outlines of the generation and selection stages are also presented.

Keywords: Operation of the steel making production · Decision making · Decomposition of optimization tasks · Engineering systems · Human-computer interaction

1 Introduction

An important component of the steel making production is constituted by slight profiles production that involves smelting and refining steel (MR), continuous casting (CC) and light profiles rolling mill (LPHM) processes. Production scheduling plays a critical role in improving productivity and reducing as possible production costs. For being efficient, scheduling must to involve the entire MR-CC-LPRM process, including heats

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production, the batches selection to satisfy customers orders between the available billets in the continuous casting (CC) process or in the warehouses inventory for being laminated in rolling mills processes (RM). In Fig. 1 the production process is illustrated.

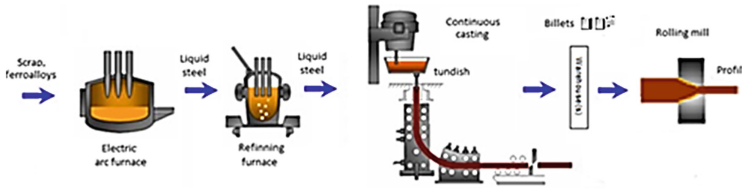

Fig. 1. Illustration of the integrated production process of SM–CC–HR complexes.

Ahead, two terms are used: a heat is a basic unit (a job of scheduling) of steel-making production and a batch is a set of heats casted continuously on the same CC installation, with a similar chemical composition. The number of heats in a batch is limited by the life-time of the nozzle at the bottom of the tundish. In last decades many works appeared linked to the scheduling problem in the MR-CC-RM complexes. Tang et al. [1] contribute a review of planning and scheduling systems for integrated steel plants, including Artificial Intelligence, Expert Systems and Constraint Programing methods; in [2] a multi-step decomposition approach for the industrial-size scheduling is proposed that include the overall MR-CC-RM where is determined the necessity of the decisions conciliation by all the fabrication stages; Zhang and Tang introduce in [3] a discrete-time scheduling formulation using a Lagrangian relaxation algorithm based on the sub-gradient method, that includes constraints concerning power availability and minimization of the energy cost, that was improved later by Mao et al. [4]. For an upstream production line in, a study of the MR-CC scheduling problem by using mathematical programming and heuristic methods are proposed by Pan in [5]. Although Jia et al. [6] and other authors model HR scheduling problem as a multiple traveling salesman problem, or close to it, Arzola-Ruiz in [7] had showed, already in 1989 year, that LPRM scheduling constitute a much more complex task. Tang and Wang [8] propose a deterministic mixed integer programming (MIP) model for scheduling production orders on some critical and bottleneck operations in a particular steel-making plant. An important component of a schedule is constituted by the match of finished and unfinished products to customers' orders. Zhang et al. [9] presente a solution scheme for matching finished production to customers' orders.

The association of the customers' orders to the unfished production (batches of billets), for previously established productions sequences, searching the minimization of the overall entrepreneurial losses linked to it, are faced by Arzola-Ruiz [10] and Zambrano-Ortiz et al. [11] and improved in the present article.

2 Destiny Options Generation and Selection

As a destiny of a batch will be understood the lamination workshop, the profile to be processed and the quality norm to be sailed a given batch of billets in process. On the destiny of a batch depend the losses associated to the excess of mechanical properties assured to the customers respecting its normed values that imply additional costs of future batch to be produced.

In the works Materials Selection in Mechanical Design and Materials: Engineering, Science, Processing and design, Ashby M.F. [12, 13] established as the best material selection options those in which the properties are used as possible fully, that means those where the excess of the properties are minimized assuring the required ones for the fulfillment it service designation. Starting from the Ashby works many authors have developed specific ideas for the solution of concrete tasks. This way, Bin [14] apply simulation techniques for studying the behavior of materials for structures using the criterion of minimizing the excess of the obtained properties respecting the required ones. Arzola et al. in [12, 13] apply this same idea for the generation of destiny options of the billets in process that are being improved in this article.

Much literature devoted to process and product management in steel-making companies, addresses the importance of accurate decision-making, however very few studies [7, 13] face this problem based on methodological approaches for the system analysis applied to the operation in real time. According these works, the decisions making tasks in organizations break down spatially: the decisions making system of the whole object directs all of the elements that conform it. At each level of space decomposition, decomposition by functions takes place, and at each level of functional decomposition, decomposition in the time is done. As a result, an interrelated decision-making task hierarchy has emerged within the same structure of the system. The spatial decomposition of the decisions making tasks determines the existence of a decisions making system of the whole organization, its subordinate tasks and a local decision-making system that participates in material production. The decomposition by functions allows to distribute the task rationally by subsystems. This production process is summarized as the preparation of certain resources for its transformation in finished production by the sales function. The resources are classified into material, technical, human, and financial functions. This way, the decisions making system of the whole company breaks down into the functional systems that cater for managing decisions regarding material, technical, humans, financial resources, production, and sales. The decomposition in time of each one of these functions leads to the determination of the tasks to be solved.

The schedules generation and selection tasks are involved in the overall planning process. The workshops' decision-making systems elaborate the productive schedules considering its functional objectives and constraints. The entrepreneurial system' schedule is selected based on the combination of proposals coming from the workshops ones, considering own objectives and constraints. The operation systems of the factory and the workshops (dispatching systems) receive real time decisions actions and must to decide which batches, from the set of available ones, must to be assigned to each customer order in such a way of satisfying entrepreneurial objectives.

Starting from the clients' orders, the productions orders for all the company workshops are elaborated and periodically rectified and. from the properties of the final production resulted, the batches are selected for the assignment to customers' orders satisfaction [9]. On the other hand, the mechanical properties of the steel depend not directly on the steel type but on the chemical composition obtained and the deformation

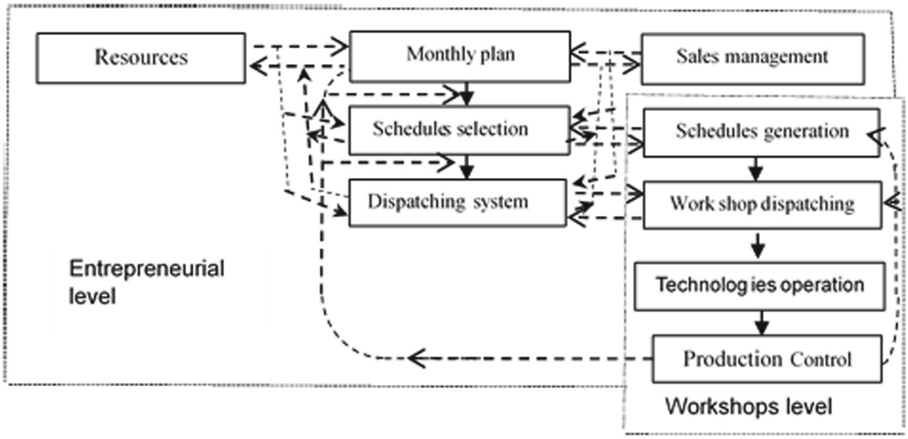

Fig. 2. Production planning hierarchy associated to the scheduling problem in steel making industry.

and thermal regimes associated to the profile production in the rolling mill process. So, the production management system must to assign production order based on chemical composition considering the technological regime associated to designated destiny. Once concluded the rolling mill process of any batch, the information about the real properties are obtained, the customers' orders to satisfy are decided and the productions orders for the remaining customers' orders are rectified, according Fig. 3.

Non-satisfied customers orders
Production orders for any and all the workshops of the MR-CC – LPRM complex
Billets batches in process
Billets batches selection for satisfying production orders
Clients orders selection, based on quality control measurements

Fig. 3. Production orders formation

The mathematical formalization of the studied problems is preceded from the external analysis of the destiny of the batches problem.

Coordination variables:

– Production orders to satisfy, that include the needed normed values of mechanical properties to be assured for the faced period (next day as a rule), corresponding to the clients orders to satisfy, with all the associated information.

Efficiency indicators:

– Minimization of the cost associated to the probable excess of properties given to the clients with regard to the corresponding to its orders (normed) that correspond to the expected amount of the expected excess. This excess could be present during a successful destination or a wrong destination that conduce to a re-destination.

Decision variables:

– Risk to be assumed of not assuring normed properties during destiny selection (subjective character decision)
– Batches to be assigned to each production order (or destiny: rolling mill to be processed, profile dimensions and normed properties to be assured).

Entry data:

– Information related to the chemical composition of the batches in process, parameters of the models that describe the properties for all the lamination workshops (rolling mills), mechanical properties corresponding to each norm adopted by the company.

3 Mathematical Modeling

Minimize the excess of all and each one of the r normed property (yield strength, tensile strength, elongation, etc.) given to the customers multiplied for the weight of each i batch, in the case of being adopted any of it j possible destinations with a probability h (assuming a 1- h risk of non-fulfillment during quality control).

$$Z_k = \sum_i \sum_j \left\{ A_h\left[R_{ijk}(x)\right] - R^n_{jk} \right\} P_i \theta_{ij}; \quad k = 1, ..., r \tag{1}$$

Assuring the fulfillment of the restrictions:

$$\left\{ A_h\left[R_{ijk}(x)\right] - R^n_{jk} \right\} \theta_{ij} \geq 0; \quad j = 1, ..., m; \quad i = 1, ..., n; \quad k = 1, ..., r \tag{2}$$

$$\sum_i \theta_{ij} P_i \geq Q_j \geq j = 1, \ \ldots, m \tag{3}$$

$$\sum_j \theta_{ij} \leq 1\,; \quad i = 1, \ \ldots, n \tag{4}$$

Where:
$A_h[\phi]$ - assured, with a probability h, value of some normally distributed magnitude ϕ.
R^n_{jk} R_{ijk} (x) – normally distributed property k of the batch i by the destiny j as a function of the chemical composition, deformation and thermal regime x associated to destiny j.

$R^n{}_{ij}$- normed value of the property k by the destiny j.

P_i- Weight (mass) of the batch i.

Q_{j} – Daily plan by the j destiny.

$$\theta_{ij} = \begin{cases} 1 - \text{if the batch } i \text{ is designated to be laminated by the destiny } j \\ 0 - \text{in other case} \end{cases}$$

Estimation of mechanical properties of the heats. Is done by radial based neural networks according to the results exposed by Jiménez-Sánchez [15], obtaining a 2,2% standard error, for 2% error of the measurement instrument. The training of these nets, treaty as an inverse problem, allows diminishing the generalized errors when applying regularization technics for solving the problem. Starting from the available mechanical properties data obtained from the quality control of the workshops and using Landweber iterative regularization method, applied to the radial based neural network training, the model that describes the mechanical properties of the heats as functions of the chemical composition and the technological process (deformation and thermal regimes, associated to each destiny) is identified for workshops adopted as study cases, between these technologies the downdraft process became the most efficient way for electric power generation. So, for estimating the s property, the following model structure is used:

$$R_k = \sum_{i=1}^{N} w_{k_{q^e}}^{(x_i - \bar{x})^2} + \lambda_k;\ k = 1, \ldots, r \tag{5}$$

Where:

$w_{i,q}^{s}$ weigh of the connection between the q hidden neuron for the i input and the k output.

$\overleftarrow{x}_i$ mean value of the x_i input variable in the original experimentation used for training the net.

σ standard error of the k output variable.

The k values obtained by these nets are about a 30% higher than the dispersion of experimental data.

Restrictions (2) assure that the assigned batches fulfill with a probability equal or more to h considering all the properties by all the designated batches.

Restrictions (3) assure the enough batches selection for the fulfilment of each one of the daily production order j.

Restrictions (4) assure that any batch could be assigned just to one destiny or not be assigned to anyone.

Objective functions (1) indicate the intention of giving to the customers' minimal possible total excess of assured, with a probability h, each one of the normed properties, considering all the daily destinies.

4 Task Decomposition and Solution Scheme

Task (1)–(4) is decomposed according the Approximate-Combinatorial method [7] by successive approximations:

- Destiny options generation for each casted batch, during the CC process that in some companies determine the length of the billet to be cut.

– Selection of the batches to be assigned to each destiny according daily production order Q_j.

The options generations is done for each batch in 2 stages:

– Minimizing only the excess of the fluency by the model.

$$\text{Minimize} \quad Z = \sum\nolimits_j \left\{ A_h\left[R_j(x)\right] - R_j^n \right\} \theta_j \tag{6}$$

Assuring the fulfillment of:

$$\left\{ A_h\left[R_j(x)\right] - R_j^n \right\} \theta_j \geq 0; \quad j = 1, \ldots, m; \tag{7}$$

$$\sum\nolimits_j \theta_j = 1 \tag{8}$$

The objective (6) considerer only the assured, with a probability equal or more to *h,* excess of yield strength limit expected with respect to the normed one of the just casted batch, starting from the measured chemical composition and the technological regime corresponding to the destiny *j*. This batch could or not to be selected in the current day or in another date, depending on the future productive situation.

Given the small dimension of the task (6)−(8), it could be solved by exhaustive search, obtaining a solutions populations for each batch of possible it destinations.

– For each solution of the population the remaining properties are calculated. If the normed value of any of the additional properties is not fulfilled, them this solution is filtered from the population. So, for each batch a population of ordered by its properties solutions is conserved.

The daily production orders must to be satisfied by the adequate selection of the corresponding batches. For solving this task the following model is formulated.
Minimize:

$$Z = \sum\nolimits_i \sum\nolimits_j \left\{ A_h\left[R_{ij}(x)\right] - R_j^n \right\} P_i \theta_{ij} \tag{9}$$

Assuring the fulfilment of:

$$\sum\nolimits_i \theta_{ij} P_i \geq Q_j ; \; j = 1, \ldots, m \tag{10}$$

$$\sum\nolimits_j \theta_{ij} \leq 1 ; \; i = 1, \ldots, n \tag{11}$$

Model (9)−(11) could be solved by Integer Programming methods, using available software. On the other hand, this model is just an approximation to the real task, by the reason the batches selection must to be done one by one, in real time, considering the newly casted batches. Supposing some solution was found by (9)−(11), every newly casted batch could change the previously decisions made. For this reason it solution is found dynamically, helped by human-computer interaction methods.

5 Human-Machine Interaction

The human-machine interaction is carried out at the higher, company dispatching, level (see Fig. 2). For each one of the j^* destiny considered in the daily plan, the available in inventory batches are ordered by the magnitudes

$$i = \arg\min_{j \in J^*} \left\{ A_h\left[R_j(x)\right] - R_j^n / A_h\left[R_j(x)\right] \geq R_j^n \right\} \tag{12}$$

Where J^* is the set of destinies included in the daily plan.

The selection of batches for any one of the destinies is made operatively considering (12) and practical situations, such as: the recommendable$h$ value for different clients, real localization of the batches in the warehouses and other considerations.

The h value selection is made searching a commitment between the intention of reducing the excess of properties resulting from a low h value, the re-assignment of customers' orders, resulting from the mechanical essays made during the quality control and other subjective considerations.

6 Conclusions

The detailed study of the state of the art evidences the deficit of works devoted to the modeling of the batches selection for the different production orders in the daily plan of steel making companies, searching the maximal employment of the potential properties that could surrender the billets in process.

The systemic analysis allows to determine the batches satisfaction for the satisfaction of the daily production orders as a component part of the scheduling problems of the MR-CC-LPRM complexes.

As an output of the systemic analysis, the conceptual mathematical model is obtained.

The systemic analysis allows to determine the selections of batches selection for the This model constitute a complex discrete optimization model, that is decomposed in a model for destination options for any of the produced batches and another for the selection of batches for each one of the destinies included in the daily production plan.

The selection of batches by destinies must to be solved by successive approximations, iteratively, considering not only the maximal employment of the potential properties of the billets in process, but also important subjectively determined indicators such as the risk to be assumed, the physical location of the batches in warehouses and other factors.

The models for determining the mechanical properties of the batches must to be rectified periodically for the adequate its adaptation to the technology development in the rolling mills of the steel making factories.

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Advantage Design of Small Commodities Under Cultural Transfer

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Abstract. Yiwu, China, is the world's largest consumer goods distribution center, and more than 2.1 million kinds of small commodities are sold all over the world. Cultural transfer refers to the process in which ideas, experience, skills and other cultural characteristics are transferred from one place to another. Due to the dual attributes of functional demand and cultural integration of products in international trade, the process of product trade is bound to be accompanied by the result of cultural transfer. In view of the urgent need for Yiwu small commodities to gain competitive advantages in international trade, according to the path of cultural transfer, using the idea, principle and technology of advantage design to put forward the advantages design strategies, such as the traceability design under the positive cultural transfer, the fusion design under the negative cultural transfer, and the system design under the two-way cultural transfer. And according to the market-oriented, forward-looking, dynamic and procedural attributes of design, the advantage design method based on the stage demand of the whole process in the future is constructed. At the same time, case studies of small commodities in international trade show that the design strategy has good application value. The research results of this paper have certain guiding significance and practical value for the future international trade of consumer goods to obtain competitive advantage, and will further improve the design level of China's small commodities.

Keywords: Advantage design · Cultural transfer · Small commodities · Competitive advantage · Design strategy

1 Introduction

With the advancement of globalization, almost every country has assumed a specific role in the international product supply system based on its own competitive advantages. Through the decades of economic reform and open up, China has developed into a world manufacturing country, especially in the field of fashionable daily consumer goods. Yiwu, China, is the world's largest distribution center for daily consumer goods, with more than 2.1 million small commodities sold throughout the world through Yiwu. These

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small commodities must not only meet the needs of users from all over the world for product functions, but also meet consumers' aesthetic recognition of product patterns, colors, materials, and forms, and their deep-level value recognition, which belong to the cultural category. Therefore, the effective integration of culture and products has become an effective means for Yiwu small commodities to gain a competitive advantage in international trade.

2 The Phenomenon of Cultural Transfer and Advantage Design Ideas in International Trade

The existence of culture, according to Ernst Cassirer [1], is the introduction of another standard of value to mankind. Ancient China opened up the 'Silk Road' by sea and road, transporting Chinese silk, tea and porcelain, products rich in Chinese culture, to the Middle East, Europe and other parts of the world, making Chinese civilization the fashion and trend of the period, and European royalty and nobility were proud to own Chinese porcelain, and drinking tea became the new way of life. Through the trade in products, new potential consumer demand was stimulated among the locals, markets for the products were expanded, and cultural migration took place, with far-reaching effects in the region. The process of product trade is therefore inevitably accompanied by cultural transfer, and its products have the dual attribute of being based on local demand for the product's function and its integration into local social life in the course of its use.

In modern times, thanks to the industrial revolution, advanced production techniques have led to a great variety of products, and trade has become an important means of economic development and cultural exchange between countries around the world. Frequent trade has led to iterations of product demand and integration, and the iterative cycle of products in international trade is becoming shorter and shorter, so how to achieve a competitive advantage in international trade, Advantage Design was born. Design for advantage refers to the design ideas, principles and techniques that create a competitive advantage for a product, a design that is geared towards market competition and the creation of a competitive advantage for the product [2].

3 Cultural Transfer in Product Design

A product is a very special carrier, which has both a practical function to meet a certain need in people's lives and a cultural carrying function to transmit the ideology of a specific group of people and the technology of a specific region to the rest of the world, so any kind of product is a specific cultural exchange messenger.

Culture is ultimately a way of life, and only when a fundamental change in the way of production is developed will the way of life migrate and the corresponding cultural forms change as a result [3]. Cultural transfer is widely understood to be the transfer of ideas, experiences, skills and other cultural traits from one society to another and from one place to another. The phenomenon of cultural transfer is the identification with the mode of production and social system behind the culture of the place of origin. Cultural transfer is an inevitable social phenomenon, with both the inevitable change in lifestyle brought about by the new mode of production, and the accidental one brought about by trade, migration, etc.

Transfer is a concept in psychology that refers to the influence of an existing body of knowledge on the acquisition of new knowledge in the learning process. The theory of transfer in linguistics was first proposed by the American linguist Robert Ledo [4]. Cultural transfer in linguistics refers to the influence of the native language culture on the learning and communication of the target language. Language transfer can be divided into two forms: positive and negative transfer [5]. The more similar the mother tongue is to the target language, the more positive the transfer will be and the more it will help the learning of the target language; conversely, the more different the mother tongue is from the target language, the more negative the transfer will be and the more difficult it will be to learn the target language.

The theory of cultural transfer in linguistics provides a theoretical basis for the study of cultural transfer in product design. Differences in cultural backgrounds such as educational and work backgrounds of industrial designers will lead to different semantic interpretations of products by destination consumers when designing products across cultures. In international trade, products as a medium or carrier of culture will, to a greater or lesser extent, adapt to the culture of the destination, and this adaptation takes the form of cultural transfer in product design. The more the cultural background of the designer is similar to the culture of the destination where the product is sold, the more positive the transfer is, and the more the design enhances the added value of the product; conversely, the more the designer is different from the culture of the destination where the product is sold, the more negative the transfer is, and even if the product has excellent performance, the consumer will choose not to buy it, and the design is not only worthless, but even hinders the sale of the product.

4 Advantage Design Under Cultural Transfer

Product design is fundamentally a cultural design of things [6]. In the past, design and production were done by a country or region, and the place of origin determined where the product was designed and where the cultural attributes attached to the product carrier were located. In modern times, due to the industrial revolution, the division of labor in society has led to a globalized pattern in the supply chain of products, with a global division of labor in design, manufacture and distribution. It is becoming a trend for products to be designed and developed in one country, standardized and manufactured in many countries, and sold globally. This division of labor is effective in enhancing the competitive advantage of products, but cultural transfer is increasingly influencing product design and placing greater demands on designers.

Edward Hall [7], a renowned cultural scientist, once said that culture is communication. The design of product advantage under cultural migration is to consider both the cultural resources of the product's origin, which we define as the first cultural attribute of product advantage design, and the cultural integration of the product's destination, which we define as the second cultural attribute of product advantage design. The first cultural attribute refers to the concept of the product and the lifestyle it leads, determined by the design philosophy of the product developer and the production process of the producer. The second cultural attribute refers to the product user's perception and acceptance of the product, which is influenced by the local cultural background and way of life. The first and second cultural attributes only represent the order of precedence and do not include their weighting. The more similar the two cultural attributes are in the process of communicating through the product as a medium, the more positive cultural transfer and the more pronounced the competitive advantage; the more different the two are, the more negative cultural transfer and the less stable the competitive advantage. A sustainable competitive advantage for a product requires a dynamic matching of two cultural attributes.

In today's globalized world, the designer characteristics of the first cultural attribute tend to be hidden, while the consumer cultural perceptions of the second cultural attribute tend to be externalized. Although positive cultural migration can enhance product acceptance, product homogenization is a serious phenomenon, and there is no difference in terms of competitive advantage. In the dynamic process of two-way migration of two cultural attributes, it will become the responsibility and goal of global industrial designers to seek the competitive advantage of products through design, based on the characteristics of marketability, foresight, dynamism and process of advantageous design.

5 Small Commodity Advantage Design Strategies and Their Case Studies

Small commodities are consumer goods of daily use and fashion that are commonly needed and accepted by the general public, including stationery, toys, kitchenware, clothing accessories, etc. With more than 2.1 million types of small commodities exported to over 210 countries and regions around the world, Yiwu, China, has an export orientation of more than 65%, making design strategies for small commodities particularly necessary. In response to the phenomenon of product-mediated cultural transfer in international trade, design is to guide the public's cultural taste in a pleasing way [8], and the involvement of design will effectively enhance the added value of small commodities, stimulate consumption and promote exports. Savitzky [9] points out that the cultural values created in any social environment are meaningful to that environment, but do not need to be accepted by all humans, so small commodity design should be good at exploring the cultural elements of each country, making innovative attempts at cultural transfer and allowing for differentiation. The author proposes a design strategy for the advantage of small commodities based on the logic that culture influences life and, through life, products (Fig. 1).

5.1 Traceability Design Under the Positive Cultural Transfer

In international trade, when the cultural perception of the destination converges with the cultural background or work experience of the designer, a positive cultural transfer of design occurs, which contributes to the advantage design of small goods. In the context of positive cultural transfer, designers can devote more energy to the study of product concepts and their production processes, the designer's forward-looking innovative design capability, which we define as traceability design. Small commodities are basically daily

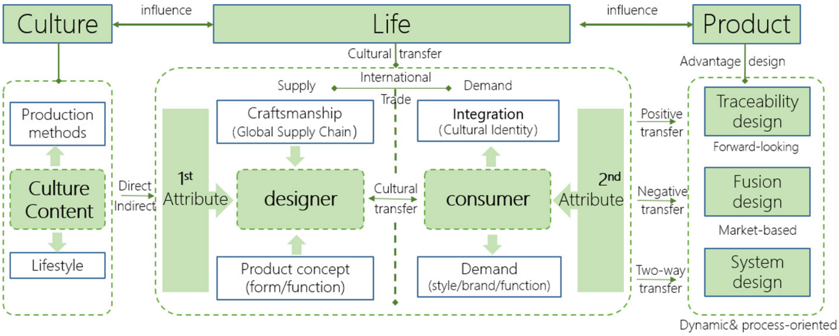

Fig. 1. Logic model of small commodity advantage design strategy

fashion consumer goods, with a short iteration cycle and a high sensitivity to popular culture, so the designer's product concept and its production process determine whether the product has a competitive advantage. The designer here comprises two categories: one is in the same cultural circle as the destination consumer, and the other is that the designer has more cases of similar designs in his or her previous work experience, and the designer has a better sense of empathy or cultural empathy and can clearly assess the destination consumer's recognition of the product design. The traceability here also includes two levels: one is the implicit lifestyle traceability, which addresses the non-material aspect of the design's cultural needs and guides consumers to pursue a better life, which is the cornerstone for inspiring the designer's product innovation concept; the other is the explicit production method traceability, which addresses the material aspect of the design's cultural needs and proposes feasible solutions for the product's form and functional realization.

As China and Japan belong to the same East Asian cultural circle, designers from both places have the phenomenon of positive cultural transfer in the small goods trade, so many small goods in Japan are not only made in China, but also designed in China, and by the same token, Japanese small goods are also very marketable in China, such as apparel and stationery. While many Western clothing brands have withdrawn from China, the Japanese clothing brand UNIQLO has achieved the number one position in the industry in China, with a market share of 1.5% in the Chinese women's clothing industry in 2019. UNIQLO's brand positioning of clothing for life, its design concept of simplicity, quality and ease of matching, and its philosophy of quality, comfort and freedom of living, as well as its low-price strategy to promote the consumption model of good products at low prices, is a lifestyle that the Chinese, and the general public, generally agree on. It is a lifestyle that is widely recognized by the Chinese and the general public. At the same time, technology is used as a selling point to establish the advanced nature of the Japanese production methods behind the brand.

5.2 Fusion Design Under the Negative Cultural Transfer

Negative cultural transfer of design occurs in international trade when there is a significant difference between the cultural perception of the destination and the cultural background or work experience of the designer, and negative transfer is not conducive to superior design of small goods. In the context of negative cultural transfer, designers need to focus on understanding the lifestyles of local people and conducting competitive product analysis, i.e. the designer's market-based innovative design capabilities, which we define as convergent design. Negative cultural transfer of designers is a relatively common phenomenon in international trade, and in response to the trend towards globalization, strategies for localization, adapting to local needs, have been proposed in order to gain a competitive advantage. Given the high substitutability of small goods and their close proximity to people's lives, the competitive advantage gained in the culturally different two-location trade lies in the need for designers to effectively match and integrate their inherent understanding of product concepts with the lifestyles of local people in design.

Peter Drucker [10] once cited a case of padlocks, a foreign export company exported padlocks to India, then sales gradually declined, the company did not design research and analysis, subjective judgment that the product quality problems, and quality improvement, and eventually led to the closure of the company. The other small company, however, made it clear through design research that for the middle- and upper-income groups in India, the lock function of the padlock was important; for the lower social classes in India, the religious symbolism was far more important than the function, and what they needed was the function of hanging. What they need is a hanging function. The different design positions of how to enhance the lock and how to facilitate the 'hang' have made this company the largest supplier of locks in India. The same padlocks are used in India due to the different lifestyles and the use of fusion design gives the company a competitive advantage in international trade.

5.3 System Design Under the Two-Way Cultural Transfer

In international trade, when the cultural perceptions of the destination and the cultural background of the designer are diverse, a two-way cultural transfer of design occurs, which has both advantages and disadvantages for the design of small goods advantages and needs to be considered comprehensively. In the context of cultural transfer, designers need to focus on the mutual influence of the two cultures in international trade, and constantly and dynamically optimize their designs. Designers are faced with a two-way dynamic process of cultural negative transfer $\leftrightharpoons$ positive transfer, which we define as the design of small goods systems.

With the development of globalization, many products have gradually lost their unique characteristics and style, which is the inevitable result of the two-way cultural transfer of system design [11]. Yellow was the color reserved for the emperor and a symbol of nobility in China, but in many countries, it was synonymous with filth. As the feudal imperial system in China completely receded from the stage of history, the Chinese gradually accepted other semantic interpretations of yellow. In addition, the dragon is the national totem of China, and the Chinese claim to be the heirs of the dragon, but in the West, it is considered a symbol of evil. Therefore, during the Beijing Olympics, although the overall form and surface texture of the Olympic torch had elements of auspicious clouds, the designers hid the cultural vein between the dragon and the auspicious clouds, and the design of the mascot avoided the dragon element. Of course, it cannot be ruled out that with the two-way migration of Chinese dragon culture, Western The dragon has been interpreted in a variety of ways in Western countries.

The origin is the initial state of a new culture, which cannot be formed and developed without the extension of other cultures, and the addition of elements from other cultures can only enrich the origin culture to form a new culture [12], or even a new culture that transcends other cultures. In 2007 Louis Vuitton launched a women's bag, priced at 26,000 RMB on the official website, and in 2016 Balenciaga also launched a bag series, priced at nearly 20,000 RMB on the official website, while this bag is an everyday storage bag used by the general public in China, priced at just 10 RMB. The Chinese plastic woven bag here is his culture, LV designers introduced this element to develop a new culture, Balenciaga designers continue to enrich this new culture, with the two-way transfer of culture, many Chinese fashionistas have also accepted this new culture, with the increase in audience, it is not excluded that one day in the future Chinese designers will also use this new cultural concept for product design, which This is the charm of systematic design in a two-way transfer (Fig. 2).

Fig. 2. Beyond culture with plastic woven bags

6 Conclusion

Culture influences life and through it our choice of small goods, so cultural engagement can lead to increased economic benefits. Design interventions are about using innovative thinking and methods to find effective strategies to increase economic benefits in different types of cultural transfer, and to guide the cultural tastes of the public in a way that is acceptable to the destination consumer. As designers, in order to gain a competitive advantage in the trade of products, it is necessary to understand the cultural background of the destination country or region, to master the use of some innovative design thinking, to develop a certain sense of 'cultural empathy' and to integrate the local culture into the multiculturalism of the world in the context of cultural transfer.

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Cognitive Living Spaces Using IoT Devices

Cognitive Living Spaces by Using IoT Devices and Ambient Biosensor Technologies

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Abstract. In the near future, our deeply connected and fully digitized physical facilities require cognitive processes that are embodied in a regular sensing of living environments. Pervasive sensor networks will enable the development of more efficient technologies that will integrate Artificial Intelligence based services better into psychosocial and human ecological contexts.

These innovative mixed and integrated biophysical and digital living spaces enable to use them more efficiently, conveniently, and, furthermore, to interpret these new intelligent environments in a completely different way. Based on the growing insight into relations between human beings and their surroundings, residents get an overview of their building ecosphere. They obtain the potential to develop strategies in context with intelligent buildings that are enabled to assist in changing behaviors in everyday life.

We study human factors, in particular, the potential of change in human behavior in such fully integrated services, strongly related to our living and work place in the case of home office. After using these sentient cognitive environments, we explore novel ways of interacting with living and work spaces by offering opportunities to give intelligent environments a virtual voice and representation via the digital data space. During the COVID-19 pandemic, people should pay more attention to their immediate living and working environment: it becomes more important to monitor the quality of the air to breathe, surroundings are made visible to get to know them better, cope better, enjoy them, etc.

The presented work provides in this context quantitative data from novel low-cost biosensors, such as for measuring carbon dioxide concentration distribution, highlighting the presence and attention of residents and their change in behavior within a sample living space, and also provides conclusions towards novel research pathways for integrating cognitive processes into a network of IoT devices and ambient biosensor technologies.

Keywords: Low cost biosensors · Data spaces · Cognitive living spaces

1 Introduction

Smart homes are becoming prominent in our daily life. However, smart home solutions tend to be very complex and experts are required to set up those systems [4]. This imposes

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the challenge about developing more intuitive interfaces, with fewer biosensors, and still be able to initiate human behavioural changes? Specifically, within the times of COVID-19 pandemics and its behavioural limitations, are such solutions usable by a non-expert? Without feedback from IoT solutions, residents tend to ignore their surroundings [5]. It is important to get enough information with few biosensors and place those biosensors well in the space given.

In the presented work, we research a coherent set of future building blocks for deeply and highly connected physical and digital cognitive living spaces. Recent advances in technologies, like the Internet of Things (IoT), connected biosensors and devices [1–3], and self-aware systems enabled new opportunities to overcome an ever-increasing complexity within these future emerging living and work spaces.

In a first step, building environments are populated with low-cost biosensors that scan the daily human biosphere regarding temperature, carbon dioxide, humidity, and the quality of air and light. In a subsequent step, we build our personal data spaces on the basis of collected digital sensor data and build novel services for cognitive living and data spaces. A starting point is the extraction of activity information from the temperature and humidity sensor context from within the living rooms. The exterior view and surroundings, such as contextual weather information, will get included as well. The availability of the data allows a number of new usage strategies, such as the analysis of long-term trends in behavior and psychophysiological parameters with regard to sleeping patterns or daily executive function assessment.

Second, these mixed and integrated physical and time-aware data spaces help us to use them more comfortably and enable new viewpoints on how to interpret these new smart environments in a very different way. Residents get an overview of their homes and the spaces they use. In this way, they gain new responsibilities (e.g. air quality, CO2 levels, humidity) and awareness about their personal ecosphere and therefore become smarter inhabitants. The experiments show that in this manner relevant parameters are better controlled for the sake of our well-being in the living spaces (home, office) and, above all, more actively. In the future, these intelligent buildings will think for themselves and assist us to change our behaviour in everyday life.

Finally, data collection and management do not provide added value for data driven applications and users by themselves. It is necessary to process these data to create meaningful services and help to make the right intelligent decisions in time. In this setting, we see data spaces, specifically, including time-aware concepts, as a key component for building cognitive living spaces. Recent advances in technologies, like the Internet of Things (IoT), connected devices, and self-aware systems brought us new opportunities to overcome our ever-greater complexity in these future living and working spaces. We need novel and intelligent services, built with the available data of these data spaces.

2 Background and Related Work

This section describes the state-of-the-art in several relevant topics in the field of time-aware data spaces and relevant low-cost biosensors.

First, data is collected, analysed, combined on various computing units, and enriched with context (e.g., time and space) information. It is fact that the data is independent from the infrastructure. To ensure time-awareness and that this data is still valid, time stamps will be added to the data sets. There are several time stamps, like creating time and receiving time. As data sets are handled between nodes in a distributed environment, each node will add a time stamp as well. Time stamped data does not require any dynamic data depended modification of the temporal workflow structure.

Second, a data space is a new approach to data management that differs from pure integration approaches. The data space approach recognizes that it is too costly to create a unifying scheme across all sources in advance. For data spaces, the focus is on coexistence of heterogeneous data. Data is integrated as required, postponing the labour-intensive aspects of data integration until required. This leads to loosely integrated sets of data sources. Data spaces were introduced by [6]. The concept of data spaces can contain different types of data sources for a person, organisation or a group of stakeholders. Data spaces work as a paradigm of a new strategy in data management and go beyond the traditional approaches. Data spaces are no static storage facilities. The semantic structure is not fixed, but is continuously updated and optimised after deployment and operation. There are a number of initiatives to establish the Data Space concept from personal data spaces [7] to industrial data spaces (see [8–10]). The future research aspects are well described in [11]. The network of data spaces is a basis for new types of eco-systems in different business domains, as discussed in several recent papers [12–14].

Third, low-cost ambient biosensors are a necessary part to produce digital data. They are the basis for enabling these digital data spaces. Biosensors can be either wireless or wired and can be deployed throughout the infrastructure, such as buildings [15]. We are interested in ideal indoor conditions [16]. Suitable indoor conditions are very essential in our cognitive living spaces. These conditions are, for example, the composition of e.g. temperature, carbon dioxide, and humidity. These properties can be changed by humans, actively by controlling some devices, e.g. opening and closing doors, cooking, using the bathroom, fans and lights, or passively, e.g. by breathing. Typical recommended temperature ranges are between 20–23 °C. This also depends on personal preferences. Based on common recommendations, carbon dioxide levels should be below 1000 ppm and humidity levels between 30% and 60% to ensure adequate indoor air quality (IAQ). The term IAQ is defined as the quality of the air inside buildings [3]. This indoor air quality is an important factor for our health, not only to particularly sensitive groups, such as children, adolescents, and older people (flats [17], schools [18, 19], homes [20]). To set up an ideal indoor sensor, we need the right environmental biosensors, such as CO2 biosensors, light, temperature or humidity biosensors. Every person emits CO2 when breathing, for example, and by monitoring changes in the detected concentration, occupancy can be inferred [2]. However, air exchange, e.g. opening a window, or weather conditions such as humidity, etc., have a decisive influence on the feasibility of this approach. In [21] strategies are reported on combining more than one technology. If we combine sensor approaches, the chosen approach with data spaces is therefore particularly relevant and certainly has great potential in this application.

3 Our Approach of Using Data Spaces

We start by calculating the activities using data from the well-placed biosensors regarding temperature, humidity, CO2, and TVOC (total volatile organic compounds) in the living areas. In addition to the interior view of our living and work spaces, the exterior view and surroundings, such as the weather, can also be included, like temperature value data. In this way, we build our necessary and personal data space. The availability of the data allows a number of new usage strategies. One can look in particular at the analysis of long-term trends in behaviour and physiological parameters, e.g. with regard to sleep or for daily activities. As an example, the following Fig. 1 illustrates a generic architecture to illustrate the next use case presented.

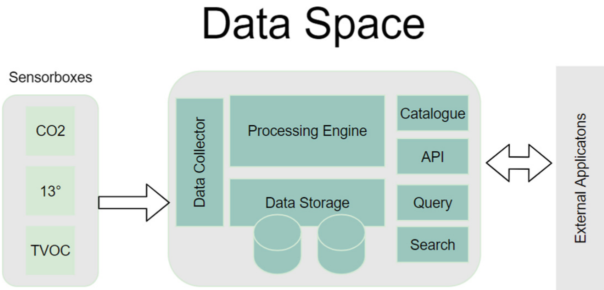

Fig. 1. Overview: Used key components of Data Spaces. The sensor box provides the raw data (e.g. temperature, CO2 level,…). Within the Data Space, all raw data and results are stored and processed. If necessary, an API is given for further analysis or providing it, if residents want to share their knowledge.

It shows the main components and services of a time-aware data space. Biosensor boxes are the devices that collect data from their environment. These biosensor boxes are usually equipped with appropriate support for data transmission. The time stamps are already added when the data is collected. In the data space, the data is stored in an appropriate raw format. A data collector is the interface for the sensor. The processing of the data is done with the processing engines in the data space. In its minimal form, the data room has a search, catalogue, and query function with appropriate API support. These APIs are the interface for external application support and offer the corresponding visualization possibilities.

3.1 User Scenario Description

We equipped our living areas with low-cost ambient biosensors to monitor them continuously. The availability of the data space allows a number of implementation strategies and especially the analysis of long-term trends and their change in behavior. In this work, we use a number of biosensors, e.g. temperature, humidity, quality of light and air, including CO2 and TVOC. Now more than ever it is important to monitor the quality of the air we breathe. The concentration of aerosols is one of the main transmission routes for COVID-19 [22], so a crucial mean of combating aerosols is ventilating the rooms on a regular basis.

3.2 Implementation of the Use Case Example

We are building the time-aware data space with data from our living areas. During the COVID-19 pandemic, we have realised how important personal well-being and the air quality in one's rooms are.

First, we collect activities of data from temperature and humidity biosensor in e.g. kitchen and bathroom. This provides us with the residents' behavior and gives the opportunity to suggest when to ventilate these rooms. The availability of the data allows a number of implementation strategies and especially the analysis of long-term trends in behavior and physiological parameters (e.g. with regard to sleep or daily activities); warnings, alarms, and reminders become obsolete in the case of home office.

Second, higher CO2 concentrations lead to premature fatigue. At even higher measurements, this can lead to headaches or other health complaints. The concentration of CO2 is one of the most common pollutants in the interior of buildings. During respiration, oxygen and CO2 are exchanged. The carbon dioxide concentration is given in ppm (parts per million). From the measured values of the indoor CO2 concentration it is possible to determine the time of arrival or departure of a person to/from the monitored room, leading to reasonable ventilation circles, which will improve the quality of living.

Third, we focus on using low-cost biosensors to create a healthy indoor environment when people are present. COVID-19 has shown how important it is to monitor the indoors and how little importance we have placed on it so far. We need a good framework for temperature, humidity, and CO2 content responsible pollutants in our rooms. With monitoring the changing situation during the seasons, an individual ventilation behavior is needed, and, depending on individual preferences, it might not be enough to simply use threshold methods. Further data collection and evaluation should improve models and therefore suggest ventilation circles.

Fourth, investigating the human side and the change of human behavior in such fully integrated personal data spaces. During the COVID-19 pandemic, an appropriate ventilation method is crucial. The question is whether such data spaces help us to change our behavior when we are responsible for good indoor air and temperature? After all, such environments are also about examining usage patterns. We expect that these mixed and integrated physical and digital cognitive living spaces help us to use them more conveniently and, furthermore, to look at new intelligent environments in a completely different way. The building residents are provided with an overview of their building and their used rooms. In this way, we hope they get new responsibilities (e.g. air because of a too high CO2 concentration) and, based on this, become a more attentive resident. These intelligent buildings think along with us and help us to change behavior in everyday life.

4 Experiments with Time-Aware Data Spaces

The test environment based on Elasticsearch is an open source distributed search and analysis engine for all data types, including textual, numeric, geographic, structured, and unstructured data. For our experiments, this is an ideal test case. The platform has simple REST APIs that can be extended as needed. In addition, this environment is distributed in nature and known for good scalability. The central component is the Elastic Stack which includes a set of open source tools for data ingestion, enrichment, storage, analysis, and visualization. Most of the data are time series with different update frequencies (as shown in Fig. 2).

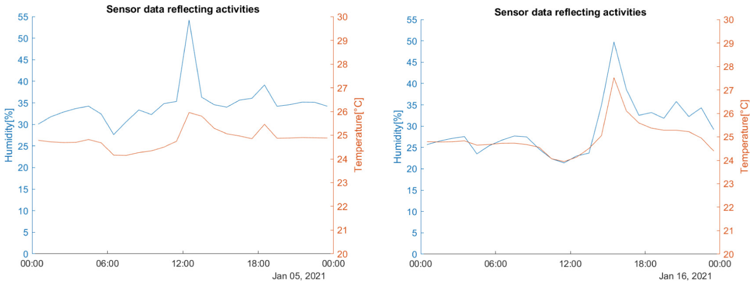

Fig. 2. Sensor data reflecting typical activities, such as, ‘cooking’ recognized by signal peaks in the data of humidity sensors. The correlated event was cooking, but other events can be detected as well, such as, ventilation. As soon as more data are sensesed, models will be updated to improve suggestions for each resident.

We use a number of low-cost wireless biosensor (e.g. temperature, humidity, light biosensor, CO2, TVOC). Collected logging data is collected in our test environment without any technical effort. Current smart home and building systems are usually closed systems, requiring a lot of effort to access the data. Due to the COVID-19 pandemic, the conducted experiments had been done during home office.

The first experiment was to find the best place for positioning. In this experiment, we changed the biosensor and finally found suitable locations in all rooms. It turned out that is useful to know the local weather condition, too. Therefore, we placed a sensor on the balcony. This one served as a kind of weather station and measured the temperature and humidity.

Second, we experimented with different low-cost biosensors and their battery life. For a wireless biosensor, the lifetime is related to the update frequency of the sensor data. They vary with measurements ranging from 5 to 30 min. For humidity in the bedrooms we set 30 min. In the bathroom and kitchen, we set 15 min. These are values that are suitable for finding useful results in the following evaluation.

In the third experiment, we have highlighted activities using simple data analysis techniques. An example regarding cooking peaks is shown in Fig. 2. The detection of cooking peaks (kitchen) or shower peaks (bathroom) works with the test data from 05/2020 to 11/2020. Due to the small amount of data, we use wireless biosensors and simple methods were chosen. For the future it is planned to use machine learning methods.

In the fourth experiment, we looked at how quickly ventilation took place after the CO2 level rose. In the course of the experiments it became apparent, that there is a change in the behavior of our active system in the long term in this home based experiments. To sum it up, this test environment proved to be very suitable for the experiments. The test environment is easy to set up by a non-expert person. With the data-centric approach of Data Spaces, the value for the user can be recognised in an adequate way.

5 Conclusion and Future Work

In this paper, we have discussed the use of biosensors in our living spaces. It has been shown that we built time-aware data spaces as a result of networked biosensors. These are important for the future consideration of many relevant smart environments.

We have described in detail a scenario from our living areas. We focus on a few key parameters, such as air quality, temperature, humidity, and light biosensors. The measurement parameters are easy to collect and highly relevant when it comes to our well-being indoors (e.g. homes, offices, etc.). In addition, we were able to show in initial experiments that this new way of looking at and using biosensor in our environment induces changes in our behavior on the long run. The initial experiments have shown that with ambient biosensors we change our behavior. However, further experiments and pilot studies with data spaces are planned and will be extended from living areas to the workplace. Finally, the dataspace concept is a key ingredient for many types of implementations. In our future work, the implementation of this novel concept of biosensor and data spaces will be extended to data spaces of buildings and smart cities. In cities, we can add new application relevant trend-setters where new concepts and efficient implementations are needed.

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Human-Centric Emergent Configurations: Supporting the User Through Self-configuring IoT Systems

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Abstract. The Internet of Things (IoT) is revolutionizing our environments with novel types of services and applications by exploiting the large number of diverse connected things. One of the main challenges in the IoT is to engineer systems to support human users to achieve their goals in dynamic and uncertain environments. For instance, the mobility of both users and devices makes it infeasible to always foresee the available things in the users' current environments. Moreover, users' activities and/or goals might change suddenly. To support users in such environments, we developed an initial approach that exploits the notion of Emergent Configurations (ECs) and mixed initiative techniques to engineer self-configuring IoT systems. An EC is a goal-driven IoT system composed of a dynamic set of temporarily connecting and cooperating things. ECs are more flexible and usable than IoT systems whose constituents and interfaces are fully specified at design time.

Keywords: Internet of Things · Human-centric emergent configurations · Dynamic generation of user interfaces

1 Setting the Context

The Internet of Things (IoT) has enabled a large number of diverse objects and devices such as sensors, actuators, appliances, and vehicles to connect and collaborate in order to support the achievement of user goals. By exploiting such things, the IoT is revolutionizing our environments with novel types of applications and services in various application domains such as building automation, transportation and logistics, healthcare, and industrial automation [1].

IoT environments are often dynamic and uncertain. For instance, the available things in users' environments might change suddenly due to the mobility of users or devices. Moreover, things' operational status might change abruptly, e.g., when they run out of batteries. Furthermore, user activities and goals might change suddenly. The former are high-level user behaviors, e.g., reading, whereas the latter represent desired effects in the user's environment, e.g., to adjust a room's light level.

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To support users in such dynamic and uncertain environments, we argue that IoT systems should be engineered as self-configuring systems with a number of desired characteristics. In this paper, we focus on the following characteristics of self-configuring IoT systems:

I. Users should be able to achieve their goals seamlessly in arbitrary environments comprising different things: For instance, a user should be able to use the same application that runs on her smartphone to adjust the light level, both in her own bedroom and in a meeting room that she enters for the first time.
II. IoT systems should not overwhelm users with requests while trying to automatically cope with dynamic and uncertain environments: For instance, an IoT system should not notify a user about how it coped with a failure of a light sensor, whereas the system should notify the user about the possibility to continue her presentation via an available smart screen after the sudden failure of the used projector. Additionally, users should also be able to easily customize their IoT systems' notification settings.
III. Users should be offered IoT services relevant to their specific context, and environments should be configured automatically according to users' preferences: For instance, a user is offered to adjust the room's light level, where she/he started reading a book. Later, according to the preferences specified in the user's profile, the light level is automatically set whenever the user performs the same activity.

Furthermore, IoT systems should be secure, privacy-preserving, and trustworthy. Devices and objects are getting connected everywhere and can collect private and sensitive data about users. Therefore, the aforementioned non-functional requirements should be first-class requirements that IoT systems should meet [2]. We plan to address the non-functional aspects in our future work.

Several approaches have been proposed to engineer self-configuring IoT systems as described in the following. Kalasapur et al. [3] developed an approach that enables the dynamic service composition in pervasive environments. The approach wraps things' capabilities into basic services modeled as directed attributed graphs and stored in a repository. To support users' tasks, the approach enables the dynamic composition of basic services into complex ones. Ciortea et al. [4] proposed an approach that wraps things as agents and enable them to collaborate to form goal-driven IoT mashups dynamically. In [5], we proposed an approach that enables the automated formation and adaptation of goal-driven IoT systems by exploiting AI-planning and ontologies. Lunardi et al. [6] developed a framework that learns the daily routines of people who suffer from mild cognitive impairments and accordingly guides them, e.g., using voice commands to perform specific tasks. Mayer et al. [7] developed an approach where things' capabilities are wrapped into semantically annotated web services composed dynamically to form goal-driven IoT mashups. Moreover, the approach enables the dynamic adaptation of the mashups apropos the availability of services. Furthermore, the approach provides an interface to enable users to express their goals in a machine understandable way. Finally, in [8], we developed an approach that recommends relevant IoT services to users based on the specific context, learns users' preferences, and configures environments accordingly and automatically.

In general, the majority of existing approaches developed to engineer self-configuring IoT systems do not address user interaction issues, rather they mostly focus on enabling technology. More specifically, the existing approaches do not investigate how the user interfaces of self-configuring IoT systems can cope with dynamic and uncertain environments. Moreover, the existing approaches do not address situations where self-configuring IoT systems cannot be dynamically formed, e.g., due to uncertainty about the user goals. Towards bridging these gaps, we present an initial approach that leverages the notion of *Emergent Configurations* (ECs) in the IoT. An EC is a goal-driven IoT system composed of a dynamic set of things that connect and cooperate temporarily. A thing is any (smart) connected object, with its individual functionalities and services or applications [5]. The user interfaces of ECs are dynamically generated and can cope with dynamic changes in IoT environments. Thus, they are more flexible and usable than IoT systems whose interfaces are fully specified at design time. Additionally, our approach uses mixed-initiative techniques where intelligent agents collaborate with users to realize ECs when partial knowledge of how goals can be achieved is available.

The remainder of this paper is organized as follows. Section 2 presents the smart party scenario. Section 3 introduces our initial approach. Finally, Sect. 4 concludes the paper and outlines some future work directions.

2 The Smart Dance Party Scenario

Some friends plan for a party on the weekend and agree to bring their own devices, such as speakers, lamps, and a tablet. Before the party starts, one or more of the organizers install an application on their smartphones or tablets. From now on, we refer to this application as the User Agent (UA). The UA automatically discovers available devices connected to the same network of the device that runs it and enables users to interact with them easily as described in the following. Via the UA, an organizer expresses her/his goal "initiate a dance party", e.g., using a voice command. The goal is interpreted, and an EC and a user interface are dynamically formed to achieve it as illustrated in Fig. 1. In the first two images, the potential constituents of the EC are displayed and the recommended settings to achieve the goal, e.g., ambient sound volume and saturation (i.e., light intensity). The selected constituents, the recommended ambient settings, and the settings of the individual devices can be customized by the organizer. Similarly, the organizer is asked to specify the device that will stream the music (e.g., her/his tablet) and a playlist. After that, the organizer's profile is updated to maintain her/his preferences and the party can be started. During the party, the organizer's tablet that streams the music is about to run out of battery, the user is notified and requested to use an alternative device. Accordingly, both the EC and its user interfaces are automatically adapted.

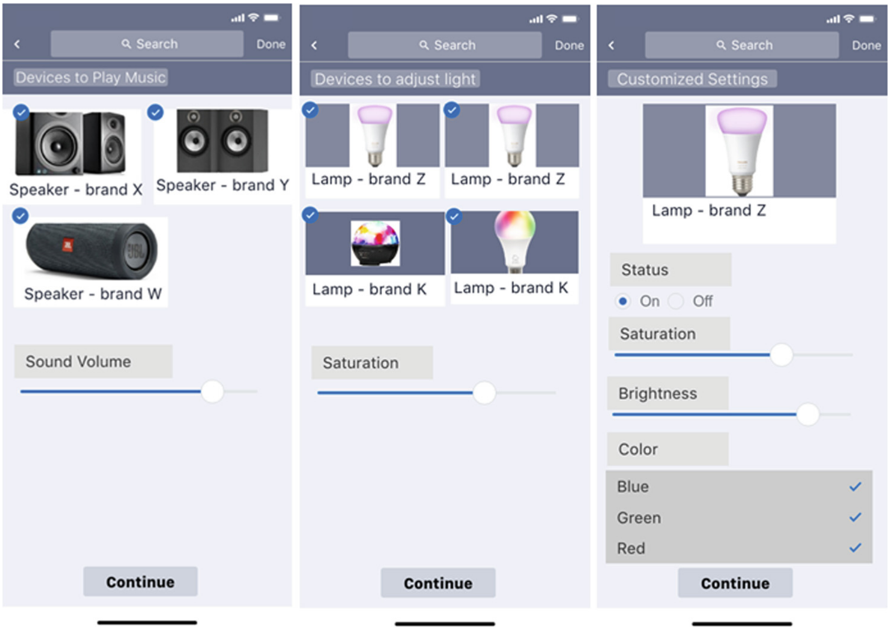

Fig. 1. The dynamic generated interface of an EC

3 Human-Centric Emergent Configurations: Our Approach

In our previous work [9], we developed an abstract architectural approach for realizing human-centric ECs. The abstract architecture of the approach is illustrated in Fig. 2. The architecture comprises a number of components. The Emergent Configuration Manager (ECM) enables the automated formation, deployment, and enactment of ECs to achieve users' goals and the adaptation of ECs in response to dynamic changes in the context. The Thing Manager (TM) registers and monitors available things and reports changes in their status to the ECM. The User Agent (UA) enables users to express their goals and

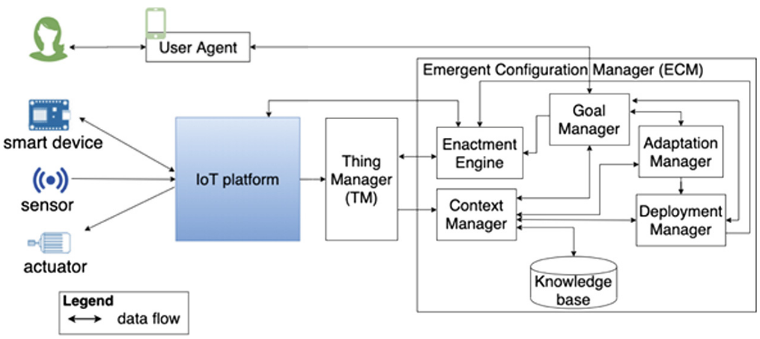

Fig. 2. An abstract architecture for realizing ECs

generates dynamically the user interfaces of ECs. We proposed a number of approaches that address different aspects and refine the ECM and TM [5, 8]. In this paper, we present another refinement of the abstract architecture, focusing on the UA. To design the architecture, we: (1) analyzed a number of human-centric scenarios, where users' environments are dynamic and uncertain; (2) iteratively developed object models for the different entities of the UA, considering the desired characteristics formulated in Sect. 1; (3) identified the UA components and specified their responsibilities. Figure 3 shows the abstract architecture of the UA, which comprises the following subcomponents:

- *Dialog Manager*. It is responsible for collaborating with users with different experience levels and possibly with special needs to specify how goals of (partially) unknown types can be achieved.
- *Goal Parser*. It is responsible for representing a user goal in a machine understandable way.
- *Event Handler*. It is responsible for interacting with users about events in their environments, e.g., it notifies a user that the tablet used to stream the music is about to run out of battery.
- *Dynamic UI Generator*. It is responsible for generating and/or adapting user interfaces for ECs, e.g., the user interfaces illustrated in Fig. 1.
- *Layout Adapter*. It is responsible for arranging and adapting the UIs presentation structure based to the device that runs the UA. For instance, the look and feel of UIs are different when shown on smartphones compared to when shown on HoloLens.
- *Action Listener*. It is responsible for handling user requests received via the UI, e.g., change a lamp's light color.
- *API invoker*. It is responsible for passing messages, including user requests, to other components, e.g., enactment engine in the ECM.
- *Knowledge base*. It comprises knowledge about supported goal types, e.g., initiate a dance party, active ECs that the UA manages in parallel, a repository of the users who use the UA, templates that provide consistent look and feel based on the type of devices that run UAs, and other resources, e.g., building constructs, that enable the dialog manager to collaborate with users to construct role-based schemas (see below).

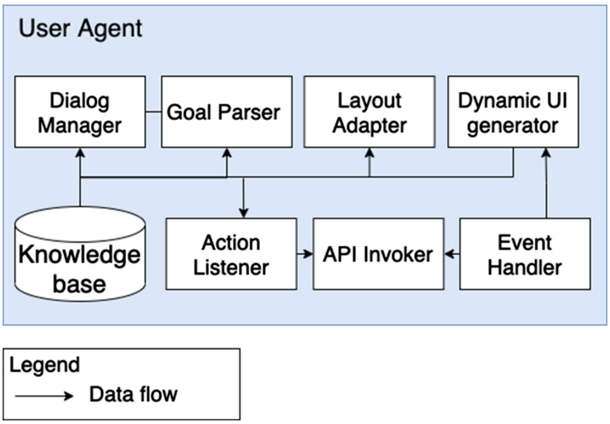

Fig. 3. An architecture of the UA

ECs are dynamically formed by instantiating role-based schemas. Figure 4 shows a representation of a schema that can be instantiated to initiate a dance party within spatial boundaries. A schema comprises roles, constraints, and a process model. A role represents a stereotype of tasks that should be performed by the assignee. A process model depicts the tasks' execution order. Constraints represent the prerequisites that an assignee should meet to play a role. For instance, to play the role "sound adjuster", a speaker should be connected and operational. A schema is instantiated by assigning dynamically the roles it comprises to (some of) available things that meet the specified constrains and have capabilities to perform the roles' tasks. For more details about the formation process, we refer the reader to our previous work [8].

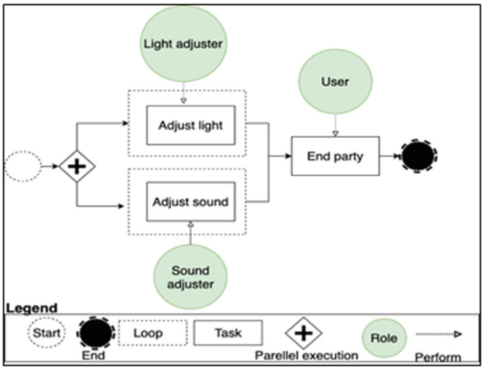

Fig. 4. A schema for initiating a dance party

When ECs are dynamically formed, their interfaces are automatically generated as described in the following. After the user expresses her/his goal to the UA, the goal is analyzed, and the process continues according to the following two cases:

1) The goal type is known to the UA: The UA forwards the goal type and its spatial boundaries to the ECM, which loads the role-based schema corresponding to the goal type and provides the user (through the UA) with a potential set of constituents that can adopt the roles in the schema together with recommended settings for the constituents, e.g., Fig. 1 left and middle columns. Then, the user can either approve the suggestions or edit and/or customize them, e.g., to adjust the saturation. After that, an EC is automatically formed by instantiating the role-based schema.
2) The UA does not know the goal, i.e., the UA confidence level is below a certain threshold: The approach exploits mixed-initiative techniques to specify the user goal as described in the following. The UA shares the user goal with the ECM, which analyzes the context, including the user's experience in specifying her/his goals and constructing role-based schemas and previous and current user activities recognized through executing pretrained Machine Learning (ML) models on the data collected by the sensors installed within the user environment. Then, the ECM applies Natural Language Processing (NLP) techniques to calculate the semantic similarity between the user goal and the goals in an ontology available in the ECM knowledge

base. Accordingly, the user is offered the top three alternative goals with semantic similarity above a certain threshold. If the user selects one of the proposed goals, the process continues as described in case 1) above. Otherwise, the user is shown schemas' building constructs, including a number of roles' tasks specified based on the performed semantic similarity analysis, and she/he is guided to construct a new role-based schema by the support of an AI planner. For novice users, information-rich means, e.g., sound and videos are used, while more expert users can be guided via text-based notifications. The user's input is continuously evaluated to determine her/his performance and if the means used to support her/him should be changed. After that, the process continues as described in case 1) above.

```
"Lamp-brand Z":{
    "UI Elements":[
        {
            "Label":"Status",
            "Type":"Radio button",
            "Options":"[on, off]",
            "inputname":"newStatus",
            "targetURL":"https://133.131.05.04:8080/ecm/enactmentEingine/changeStatus?status
              =newStatus"
        },
        {
            "Label":"Saturation",
            "Type":"Range slider",
            "Options":"[Min: 0, Max: 254]"
            "inputname":"newSaturation",
            "targetURL":"https://133.131.05.04:8080/ecm/enactmentEingine/changeSaturation
              ?saturation=newSaturation"
        },
```

Fig. 5. Part of a lamp UI model in JSON

After an EC is dynamically formed, the UA retrieves the things' UI models from the TM. Those models are defined by developers or things' manufacturers and include basic UI properties used to dynamically generate interfaces for ECs. Figure 5 shows part of an example of a lamp UI model expressed in JSON. The dynamic UI generator parses the UI properties and choses proper UI elements based on the type of the device that runs the UA. Accordingly, the layout adapter arranges and adapts the UI presentation structure and renders it to the user. After that, the EC is enacted by the ECM. The UA, TM, and ECM continuously monitor the context and adapt the EC in response to changes in the environments by executing Monitor-Analyze-Plan-Execute plus knowledge (MAPE-K) loops.

4 Conclusions and Future Work

In this paper, we proposed an approach to support users to achieve their goals in dynamic and uncertain IoT environments. The approach enables the dynamic formation and adaptation of both ECs and their interfaces based on the context. Consequently, ECs are more flexible and usable than IoT systems whose constituents and interfaces are fully specified at design time. Additionally, the approach supports the automated configurations the environments according to the users' preferences.

As future work, we plan to continue investigating how to realize the proposed approach and address the following challenges. First, techniques are needed to determine the competences of new users in interacting with IoT systems in arbitrary and dynamic environments. Second, users can be part of IoT systems e.g., when they perform tasks that are not automated or provide information about their environments. Therefore, methods are needed to determine how users can be involved to achieve goals but without being overwhelmed with many requests. Third, non-functional requirements, such as security, privacy, reliability, and trust should be considered when realizing human-centric ECs. Finally, we plan to investigate how user agents can share the knowledge they learned while supporting users whose goals were not fully known to them. Applying Federated learning techniques is a possibility for this purpose.

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Playful Screening of Executive Functions Using Augmented Reality and Gaze Based Assessment

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Abstract. Augmented Reality (AR) technologies have recently been explored for application in dementia care, including cognitive training and screening, navigational assistance to find their way around, assistance to identify friends and family members, and assistance with activities of daily living. The presented work proposes the use of mobile and playful assessment of executive functions in the home environment by AR technology. We implemented a gamified version of the neuropsychological test 'Tower of London' (Shallice, 1982 [1]). It is played with poles of various size and colored balls, starting each exercise with a certain start and desired goal configuration of balls on poles. The novel AR-based technology enables hand-based interaction with artificial objects in the field of view and monitoring of the user's gaze behavior via eye tracking towards the artificial objects of interest. A pilot study was performed with 12 healthy people that played the game with various degrees of difficulty concerning its planning depth. The results of the study demonstrate statistically significant correlation between the eye tracking features and the planning ability as well as cognitive flexibility measured by standardized psychological tests. This study provides first indication that executive functions can be estimated from playful AR-based interaction. Future work will focus on adjusting the game for persons with dementia, such as, by decreasing the difficulty level appropriately.

Keywords: Augmented Reality · Eye movement analysis · Mental health care

1 Introduction

Dementia rates burden global health care resources to a serious degree. Providing adequate and sufficient care, especially in one's own living environment, is one of the greatest technical and social challenges. Multimodal intervention strategies combining cognitive, physical and social stimulation in an early phase promise significant potential for success [2]. A major objective is to provide non-pharmacological intervention strategies for living at home for a long time, measure the progression of dementia and adjust interventions accordingly. Executive functions (EF [3]) include the ability to adapt

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to changing demands of activities of daily living (ADL) through cognitive flexibility, working memory, cognitive inhibition, task switching, or inhibitory control. Executive dysfunction is a significant predictor of future deterioration in mental states of dementia [4, 5]. Meaningful requirements and possibilities of use of AR technologies for persons with dementia have been increasingly mentioned and described [6] including cognitive training and screening, engaging in hobbies, providing navigational assistance to find their way around, assistance to identify friends and family members, and assistance with ADL [7, 8].

The presented work implemented a gamified version of the neuropsychological test 'Tower of London' (TOL [1, 9]) using AR-based technology with the purpose to enable the screening of EF in a playful manner (Fig. 1). Various levels of difficulty require increasing planning depth to attain the end configuration. The gamified test was implemented with hand-based interaction and assessment of eye tracking features during the game. The presented work developed a version for healthy people to firstly test validity of EF assessment in general.

The EF of N = 12 healthy participants were firstly analyzed by planning ability (standardized version of TOL) and cognitive flexibility (Trail Making Test, TMT). Thereafter, they participants played a game version of TOL in AR.

The results of the study demonstrate statistically significant correlation ($\rho = -.833$, $p = .001$***) between the reference TOL's planning ability parameter and the AR-TOL's gaze time during execution while "looking back" to remember details in the target configuration. The gaze time during an inhibition related game part correlates with TMT's measure (time for test "B") for cognitive flexibility ($\rho = .636$, $p = .030$*).

This study provides first indication that executive functions, such as, planning ability, can be estimated from playful AR-based interaction. Future work will focus on adjusting the game for persons with dementia, such as, decreasing the difficulty level appropriately.

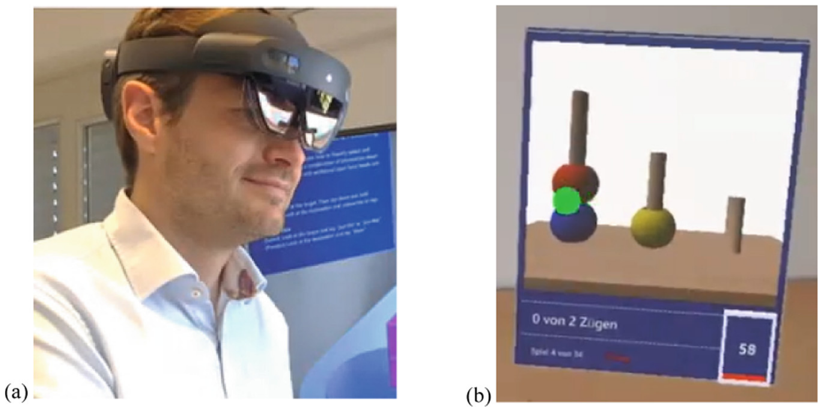

Fig. 1. Augmented Reality (AR)-based playful assessment of executive functions using the Tower-of-London neuropsychological test [1]. (a) The AR-based platform Microsoft HoloLens 2 enables eye tracking with respect to 3D holograms in the view. (b) Eye fixation (green) on artificial object with goal configuration and status report.

2 Context and Related Work

Individuals in the early stages of dementia are primarily cared at home (WHO [12]). One of the most important tasks of nursing care is to promote the independence of persons with dementia, taking into account the stage of dementia and individual abilities. Such care can counteract a too rapid increase in care dependency [21]. Intelligent technologies for augmented reality based assistance should support persons with dementia and empower their self-efficacy. Training apps and assessment facilities are important to support the user's control and provide insight into the course of the disease or preventive measures.

Dementia is a condition that affects and limits a person's skills to perform ADLs successfully [13], with problems in executive functions possibly being more problematic than memory problems [14]. The assessment of EF is critical for the functional performance of ADL in dementia and is recognized as an important aspect and may be useful for early detection of Alzheimer's dementia (AD). EF encompasses a wide range of abilities, the number and type of which vary according to different authors. A number of interrelated skills have been distinguished in the literature, including recognition and selection of appropriate targets, manipulation of concurrent information (e.g., shifting sets, sequencing, and monitoring), attention directed to cues, concept formation (e.g., abstraction) [3]. EF involve strategic planning, impulse control and organized search, and flexibility of thought and action [1].

Meaningful requirements and possibilities of use for dementia sufferers included, (i) cognitive training and screening, (ii) a resource for engaging in hobbies, providing (iii) navigational assistance to find their way around (at home and outside), and (iv) assistance to identify friends and family members, and (v) assistance with ADL which have been increasingly mentioned and described [6–8]. AR-based technologies are considered as a "cognitive prosthesis" for people with dementia, particularly as an assistance in ADL. Boletsis & McCallum [6] have particularly developed an AR-based gaming experience. Altoida AG (Lucerne, Switzerland; San Diego, USA) is a dedicated company in the field of augmented reality assisted assessment for Alzheimer's disease [15] and won the EIT Innovation Award 2018.

3 AR-Based Gamified Tower-Of-London

3.1 The Tower-Of-London (TOL) Test

Individuals must maintain a smooth flow of planning and control behavior in the face of potential distractions. At each step of the task, they must obtain relevant information with respect to their goal (or sub-goals); on the other hand, they must suppress irrelevant information. Moreover, the immediate achievement of a sub-goal may conflict with the achievement of sub-goals leading to the final goal. Within the broad EF framework, the TOL test addresses a central feature of EF: planning skills that imply achieving a goal through a series of intermediate steps. Intermediate steps that do not necessarily lead directly to that goal. To examine this type of process in EF, Shallice (1982) developed the Tower of London (TOL) test.

This TOL test was developed as a means of identifying impairments of such higher-level planning processes. It was derived from the Tower of Hanoi disk transfer task, which consists of well-defined start and goal states, and a constrained set of legal operators (i.e., behavioral responses) for movements through the problem-solving space. TOL requires planning, such as means-ends analysis, to solve a set of successively more difficult problems and to avoid wrong moves. Solving TOL problems requires rearranging colored balls on three pins to match a target arrangement. Arranging (i.e., duplicating the experimenter's ball configuration) the balls on an adjacent model (starting position). The simpler problems can be solved by directly transferring balls from a starting position to a target position, while complex problems require planning the correct sequence of moves. In these cases, the goal is achieved by decomposition into sub-goals. The TOL is a nonverbal task. It is a new task for all subjects, so subjects did not have the opportunity to develop subroutines beforehand.

The TOL test is well suited for assessing EF, which is an important clinical aspect in AD. However, it may use a simplified version of the task in this population. Rainville et al. [9] examined EF deficits in AD using a new adapted version of Shallice's (1982) TOL test. That version followed a "hierarchical paradigm," that is, simpler problems are embedded in more complex, subsequent problems.

The goal of the proposed work is to enable a more playful version of the combined training and assessment which should in principle enable increased adherence to useful training through joyful play and more variation in the setting of the trials.

3.2 AR-Based Technology Implementation

In a first step, the user of the AR-based Tower-of-London (AR-TOL) in the role of the moderator positions the HoloLens in space. The moderator defines the world anchor (coordinate origin), which is positioned by hand as agreed upon. As a world anchor, a representation of the game board is positioned and the coordinates are stored on the device. A next step is the calibration of the eye tracking data with respect to the anatomical configuration of the user's eyes and the geometry of the HoloLens device. Actually, the user has only to calibrate once since the HoloLens memorizes the individual configuration and immediately recognises a user at any future time of use. Finally, the transmission of eye tracking and event-based data to a server is initiated.

The user is then guided to an introductory component of the app where she can accommodate with the user interface and the requirements of the game. In particular, the user can play several single trials with planning depth of 1, 2 or even 3 moves. The interaction device is the user's hand which is automatically recognised by the device including gestures like grabbing and dragging. This enable the user to grab a ball and move it to the desired target pole. Virtual buttons are displayed for specific decision making, such as, for early finalising the current trial. A status board ("area-of-interest", AOI) is displayed representing the to-be-attained goal configuration of balls on poles, as well as demonstrating the required number of steps to the goal and the time elapsed. Numerous events - like starting to grab a ball, or leaving the ball to snap onto to a pole - are logged to the server with the time stamp of the device, together with eye tracking information, most importantly, the orientation of the gaze ray and the intersection with artificial 3D objects in the scene (ball, pole, AOI).

The app offers currently a sequence of trials with varying difficulty, i.e., the planning depths related to the expected number of moves, to complete the trial. Currently, the app is configured for healthy users, i.e., with more difficult trials. There are 8 trials each with planning depth of 4 (“L4”), 5 (“L5”) and 6 moves (“L6”) to play.

4 Eye Movement Analysis for Cognitive Assessment

Recently, numerous methods of attentional analysis using laboratory-based eye-tracking technology have been developed, but there is still a lack of a way to pervasively and continuously track the mental state of people living at home or in nursing homes to detect rapid cognitive decline that can occur within months or even weeks. One potential solution is video-based rapid assessment of cognitive impairment using eye-tracking, which was recently introduced [10]. Furthermore, [11] highlights the importance of continuous assessment supported by gamified interaction within a game component. It presents a game-based version using an eye-tracking camera embedded in the device to capture and analyze eye movements during gameplay. The specific gaze task is known to detect impulse control problems as seen in neurodegenerative diseases associated with EF.

The goal of analyzing eye-tracking data during AR headset use is primarily to characterize gaze behavior through typical features of eye movements and to interpret it in terms of cognitive psychology-based constructs. The primary goal of the interpretation is to provide features that would be correlated with features from the scores of questionnaires - especially regarding TMT and TOL (Sect. 5).

5 Experimental Results of Pilot Study

Technologies. The study was performed with the Microsoft HoloLens 2 that is a pair of mixed reality smart glasses. The device is a high-resolution stereoscopic 3D head-mounted display, with a diagonal field of view of 52°, with integrated sensors, speakers and its own computer unit, i.e., the Holographic Processing Unit (HPU) 2.0. The HoloLens therefore does not require an additional PC and works wirelessly, it weighs 566 g. It is supported by a Natural User Interface being operated via gestures, speech, head movements and small buttons. It enables eye tracking, fully articulated hand tracking, semantic labelling, and spatial audio. A complete app was developed for a fully independent service for the gamified version of the Tower-of-London (TOL) psychological test, i.e., AR-TOL. It firstly enables to root the holographic projections with respect to a local 3D anchor, receives user specific input and starts the wireless transmission of eye tracking, interaction and event data to a server based computing unit. The app can be used by a single person. A video stream connectivity was implemented to transmit the egocentric view of the user with holographic and eye tracking information to a nearby PC for monitoring purpose (Fig. 2a).

Methods. The pilot study was performed with N = 12 healthy participants, 33.3% females, with M = 49-9 (SD = 9.3) years of age. Participants were recruited at an applied research centre with employees having on average 20 years of IT research experience. Ethical approval was granted by the Ethics Committee of the Medical University of Graz (EK number 32-166 ex 19/20) and Information Consent received. The questionnaires

Cyber Sickness Questionnaire [16], Affective Slider [17] and System Usability Score [18] were filled before/after the TOL trials session. Furthermore, the Trail Making Test (TMT [19]) was applied for assessment of visual search, attention, mental flexibility, motor skills and EF. Finally, the standardised form of the TOL was tested, i.e., the Freiburg version of the TOL-F [20] according to the Vienna Test System (VTS), a test system for computerized psychological assessments. Before the AR-TOL trials session, participants were briefly introduced, played 6 easy trials to be introduced into the user interface and the game. Thereafter, they played trials with various planning depth and therefore complexity, i.e., 4 x L3 (planning depth 3 moves), 8 x L4, L5, L6, inspired by the TOL-F [20]. During AR-TOL play, the planning, action and inhibition time were measured: planning time refers to the time between trial start and start of first move, action time is between end of planning time until trial end, and inhibition time refers to the part of action time in which no ball was moved being dedicated to re-planning time. Please note that all following quantities related to TOL - TOL-F and AR-TOL, respectively – relate exclusively to the interaction time playing the most difficult trials (L4, L5, L6) in total, not in detail.

Descriptive Statistics: The time spent (in sec.) for TMT-A was M = 18.9 (SD = 3.4) and for TMT-B M = 24.8 (SD = 6.8). Percentile rank results from comparison with the representative norm sample of the TMT of the VTS were for A-PR M = 52.3 (SD = 20.4) and for B-PR M = 70.3 (SD = 21.0). Results of the TOL-F of the VTS were number of correct trials (M = 69%, SD = 11%), planning time (in sec.: M = 7.7, SD = 2.9), action time (in sec.: M = 8.1, SD = 2.6). Percentile rank results from comparison with the representative norm sample of the TOL-F of the VTS were for planning ability M = 66.9 (SD = 22.5) and for correctness M = 75.4 (SD = 16.9). The usability was measured with the System Usability Score (SUS [18]) and resulted in M = 84.8 (SD 7.3) proving good acceptance. Comparable results of the AR-TOL HoloLens experience were number of correct trials (M = 63%, SD = 17%), planning time (in sec.: M = 10.6, SD = 1.9), action time (in sec.: M = 13.7, SD = 5.1), and inhibition time (in sec.: M = 7.7, SD = 4.3). Furthermore, basic eye tracking features were measured, such as, gaze time (in sec.) within the area-of-interest (AOI, Fig. 2b) per trial for planning (M = 4.5, SD = 1.7), action (M = 3.1, SD = 1.8) and inhibition (M = 2.3, SD = 1.8) time; and number of visits of the AOI per trial for planning (M = 7.0, SD = 2.8), action (M = 6.5, SD = 2.9) and inhibition (M = 5.1, SD = 2.7).

Inferential Statistics: In general, the AR-TOL evaluated highly similar to the standardised TOL-F of the VTS, among others, with their correct rate (her and below always Spearman's: $\rho = .641$, $p = .025$*) and planning time ($\rho = .832$, $p = .001$**) correlating significantly.

The most important observations demonstrated that eye movement features, derived from the eye tracking measurements, showed statistically (highly) significant correlations with parameters that were previously derived exclusively from standardised psychological tests. Gaze time during planning (AR-TOL) correlated with the median planning time (TOL-F) by ($\rho = .785$, $p = .003$**), gaze time during inhibition (AR-TOL) with the time to process TMT-B by ($\rho = .636$, $p = .030$*), number of visited AOIs during action time (AR-TOL) with percentile rank results for planning ability by ($\rho = -.833$, p

= .001***), and gaze time during inhibition (AR-TOL) with the time to process TMT-A by (ρ = .622, p = .035*).

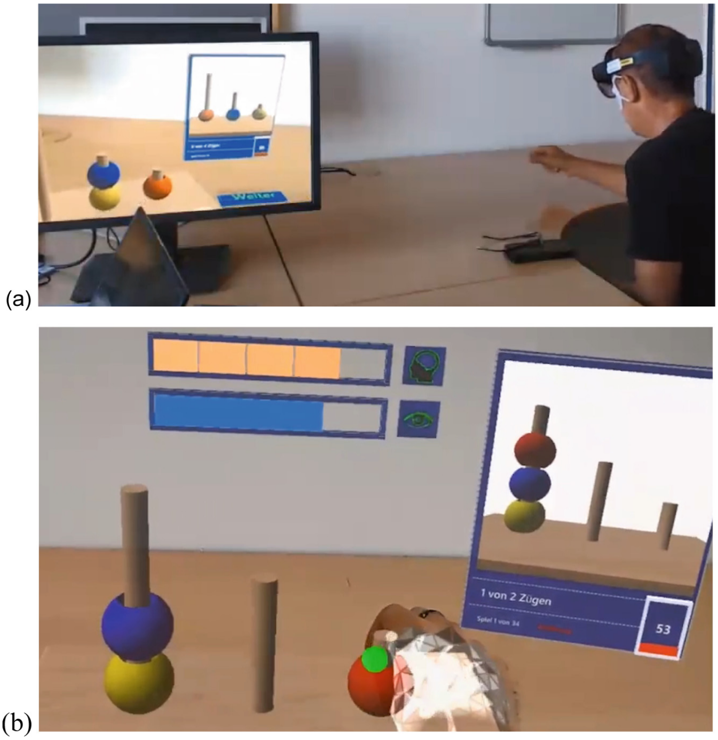

Fig. 2. AR-TOL app: user interface and study experience. (a) Participant of the pilot study in interaction with real-time visualisation of its egocentric field of view including augmented reality information. (b) Monitoring information including gaze pointer (green) and indicative gaze features (top bar: concentration, below: saccade rate) in the field of the user's view.

6 Conclusions and Future Work

The pilot study with AR-based technology demonstrated that important parameters of executive functions could be measured on the basis of eye movement features. This indicates a large potential for mobile non-invasive and playful assessment for decision support. The described AR-based training component anticipates numerous opportunities for novel AR-based care services and as pervasive assessment tool. Future work will focus on extending the gamification aspect of the training scheme and enabling more extended and profound analysis of eye movement features.

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Advanced Cyber and Physical Situation Awareness in Urban Smart Spaces

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Abstract. The ever-growing adoption of big data technologies, smart sensing, data science and artificial intelligence is enabling the development of new intelligent urban spaces with real-time monitoring and advanced cyber-physical situational awareness capabilities. In the S4AllCities international research project, the advancement of cyber-physical situational awareness will be experimented for achieving safer smart city spaces in Europe and beyond. The deployment of digital twins will lead to understanding real-time situation awareness and risks of potential physical and/or cyber-attacks on urban critical infrastructure specifically. The critical extraction of knowledge using digital twins, which ingest, process and fuse observation data and information, prior to machine reasoning is performed in S4AllCities. In this paper, a cyber behavior detection module, which identifies unusualness in cyber traffic networks is described. Also, a physical behaviour detection module is introduced. The two modules function within the so-called *Malicious Attacks Information Detection System* (MAIDS) digital twin.

Keywords: Internet of Things · Artificial intelligence · Edge computing · Crowd behavior · Digital twins

1 Introduction

Current urban environments do require 24/7 guaranteed safety and security of citizens for using smart spaces, operational systems and services. These constitute smart cities main infrastructures such as transport networks and their multi-modalities (motorways, rails, airports or maritime ports), energy and water supply networks; hospitals as well as spaces with public character or the so called "soft targets" such as malls, open markets, pedestrian precincts, city squares, sports venues, tourist sites and more. The provision of guaranteed 24/7 safety and security in the smart city spaces is of paramount importance for all citizens to confidently participate, cooperate and effectively contribute to the sustainable progress of the city socio-economic activities. Nevertheless, and with the ever advancement of smart city technologies, together with the mass deployment of IoT technologies, cities operations and services are being transformed at unprecedented rates

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and scales. Hundreds of thousands of connected systems are being embedded in many cities critical infrastructures, for urban planners and security practitioners improve their operations to assure safety of citizens. Nevertheless, while these emerging technologies are bringing increased operational efficiencies, smart city infrastructure have become vulnerable to new threats and attacks on soft targets such as crowded city open spaces. On July 14th 2016, a 19-tonne cargo truck was deliberately driven into crowds of people in Nice, France, which resulted in 86 fatalities: An attack considered as a "*physical attack"* at a city open public space [1]. While on May 13th, 2017, the German transport system, specifically the electronic travel announcement boards at train stations, which started in Berlin, were completely crippled by a ransomware: An attack that is indeed a "*cyber-attack"* to a city public transport [2]. These types of cyber-physical attacks, have also occurred in other locations in the world in recent years. They present a threat to safety and security while they raise the concern of high vulnerability and risks of attacks to which urban spaces and infrastructure may be exposed.

2 S4AllCities Project

The S4AllCities project [3] was launched in September 2020, as a large consortium of 27 partner organizations from academia and industry in Europe. One of the main goals of the project is to deploy automated, scalable and performing captures of real-time intelligence for safety and security in urban smart spaces environments. Three European pilot cities with respective urban smart spaces were selected for demonstrating our S4AllCities technology by the fall of year 2022. These include: The City of Bilbao, Spain; Trikala Municipality, Greece; and the City of Pilsen, Czech Republic.

The S4AllCities technology adopts a distributed and interoperable System of System (SoS) architecture which is driven by three major Digital Twins; each of which specialises in levels of situation awareness and uses computer machine intelligence. Together, they revolutionise the way cities enhance strategic protection, preparedness and resilience against cyber-physical threats and potential attacks on urban smart spaces and critical infrastructure networks. The three Digital Twins are:

a) Distributed Edge Computing IoT Platform: *DEC_IoT*
b) Malicious Actions Information Detection System: *MAIDS*
c) Augmented Context Management System: *ACMS*

They function intelligently on the following levels of situation awareness in context of the smart spaces environment respectively:

a) *DEC_IoT* → Processing of observed events in the urban smart spaces
b) *MAIDS* → Intelligent detection and understanding of unusual behavior
c) *ACMS* → Augmented realization of intelligence for threat alerts

2.1 System of Systems Architecture (SoS)

Real-time intelligent detection and understanding of observed processes in urban smart spaces are being experimented in the S4AllCities project. As shown in Fig. 1, below, the SoS connects to the urban smart spaces physical IoT with all the relevant sensing networks; operational legacy systems and critical infrastructure information and communication networks. The generated data streams are ingested by the DEC_IoT twin and aggregated intelligently on the edge for further diagnosis by MAIDS twin through a message broker middleware. The DEC_IoT is event-driven while it dynamically emulates a problem environment which is representative of the smart environment of interest and to which one subscribes. The subscription of the MAIDS to it leads it to enacts further processing for unusualness detection and understanding of physical motions of objects, individuals, clusters of individuals and overall crowd in the smart environment. It assesses cyber traffic unusualness in communication networks which function within the same smart environment too. The overall states of unusualness of both cyber and physical detections may also require high data fusion and knowledge modelling and reasoning in order to obtain an accurate context understanding of the nature of unusualness as potential threat and/or attack on the smart space.

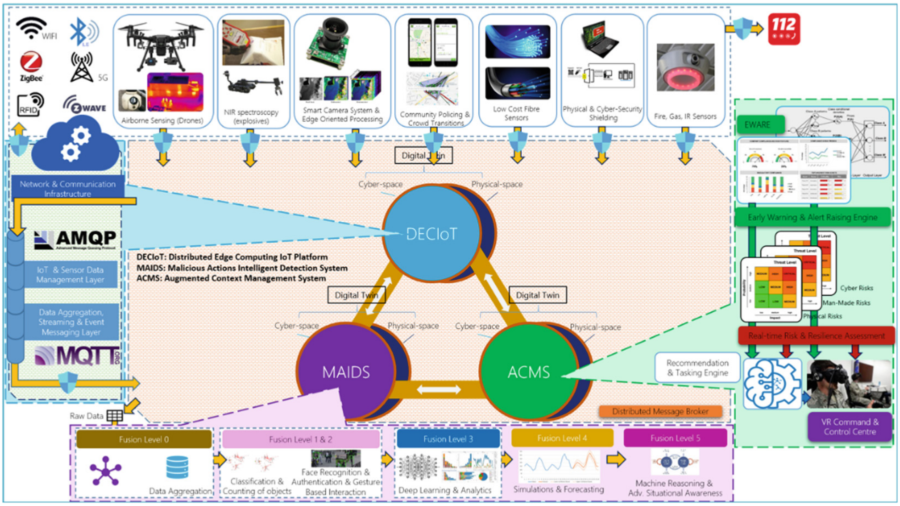

Fig. 1. S4AllCities SoS high level architecture with its three digital twins

The This results into stream messaging such information from the MAIDS to the ACMS twin for realizing a real-time augmented contextual understanding of the smart environment. This is what is called the Common Operational Picture (COP).

2.2 IoT and Edge Computing

Over the past years research and technological advancements have enabled the paradigm of Internet of Things (IoT) to transition towards higher technological readiness levels by addressing key underlying issues. With respect to hardware components, the reduced cost of sensor, compute and communication components enables the development of low-power, highly embedded and affordable IoT devices with small physical form factor that can be deployed *en masse*. This underpins the development of cyber-physical systems, that are well-integrated in the physical environment and seamlessly interconnected with other digital systems. In this context, the emergence and high adoption rates of Single Board Computers (e.g. Arduino's and Raspberry Pi's) allow the deployment of embedded devices with considerable compute resources at the fringe of the IoT network, able to support sophisticated services, such as localized data processing and decision making. Advances in the area of Low Power Wide Area Networks (LPWANs) have fine-tuned the trade-off between energy consumption and long-range wireless communication of IoT devices, thus facilitating the deployment of IoT systems over wide areas, spanning across urban regions. The variety of available solutions accommodates diverse requirements not only from a technical perspective but from an operational one as well. For instance, LPWANs operating in the unlicenced spectrum (e.g. LoRaWAN and Sigfox) allow the deployment of private standalone IoT systems with low operational costs. On the other hand, LPWANs operating in the licenced spectrum (e.g. NB-IoT) allow quick and scalable deployment of IoT systems over the existing cellular infrastructure. In the context of 5G networks, the interconnection of such IoT systems with backhaul networks and backend systems underpins the interplay with next Generation Networks (e.g. Software Defined Networks and Network Function Virtualisation), other technological enablers (e.g. Edge Computing, Big Data Analytics and Machine Learning) as well as more agile development tools and methods, such as the use of micro-services and containers.

The aforementioned advances shape a technological ecosystem for cyber-physical systems that not only are able to collect sensory data from the physical environment but can process this data and take decisions locally. This is highly relevant since IoT data are typically characterized by timeliness and their value is highly localized [4, 5].

S4AllCities introduces the DECIoT Digital Twin which builds upon a collection of open source micro-services that span from the edge of the physical plane. The use of the EdgeXFoundry Platform disassociates the physical IoT devices from the generated IoT data by obfuscating implementation complexities and dependencies via standardised south-bound and north-bound interfaces. This modular architecture supports data and event-driven decision-making at the Edge as specialized services (e.g. machine learning models) that typically reside on the Cloud can now be deployed closer to the data sources for intelligent pre-processing.

2.3 Data Fusion, Modelling and Reasoning

Multi-level data fusion which adopts the *De-Facto* Joint Director of Laboratory (JDL) data fusion framework has revolutionized the way we intelligently advance situation awareness [6]. While, the Endsley model is well-known for advancing situational awareness in context of critical decision support on cyber or physical security it can be mapped onto the JDL model, for equivalence, as illustrated in Fig. 2. The JDL framework offers a more adaptive approach to intelligent data processing, i.e. multi-level fusion, and interpretation of progressively advanced situational awareness which can be applied to cyberphysical security [7, 8]. With the recent advancement in IoT, large streams of big data can be generated and from which critical knowledge can be extracted in real-time using machines reasoning in order to understand threats and/or attacks on urban spaces with high context awareness [9, 10]. The MAIDS twin of S4AllCities SoS, adopts the JDL data fusion framework, for big data processing and analytics while it can efficiently organize them at various fusion levels, which themselves are levels of cyber-physical situational awareness. These include: *Level 0: Pre-processing; Level 1: Object Assessment; Level 2: Situation Assessment; Level 3: Impact Assessment; Level 4: Context Refinement and Level 5: User Refinement.* These respectively cover equivalent levels situational awareness that concern*:* 1 - Perception; 2 - Comprehension; 3 - Projection; 4: Decision; and 5 - Performance feedback.

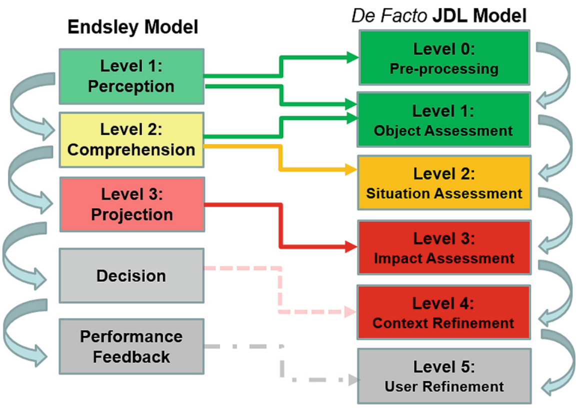

Fig. 2. Endsley model equivalence with the JDL for advanced situational awareness

However, the most important element for the successful deployment of framework, for the detecting and understanding unusualness in the cyber and physical environments is the acquisition of quality observation data. Such quality data is expected to uniquely manifest key features of physical and cyber behaviour in context of urban smart spaces in order to achieve performing machine learning algorithms. Without which we will not be able to select the correct optimised features and generalise the algorithms into pergreat Correct Classification Rates (i.e. CCR > ~90%) of unusual behaviours.

3 Cyber Behaviour Detection

The growth of smart spaces brings with it a massive increase in the adoption of IoT and ICT technologies. Coupled with an ever-growing issue of cybercrime there is an inevitable exposure to a vast number of cyber-attacks within smart spaces due to their large surface area for attack. With smart spaces being at the forefront of today's technology it is only natural for cybercrime targeting these spaces to become more sophisticated too. To protect the smart space, its critical infrastructure and communication networks equal sophistication is required, basic defences would not be suitable. A scalable incident detection solution will be implemented for S4AllCities, it will be able to detect unusualness in the network using machine learning. It will also be able to grow and adapt to handle ever-increasing amounts of data.

3.1 High-Level Architecture

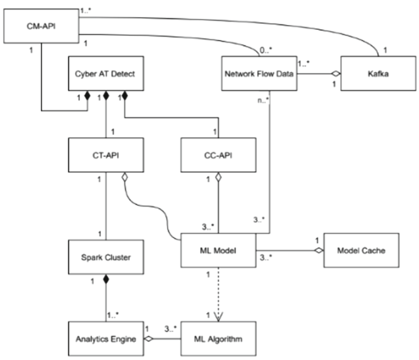

Fig. 3. High-level class diagram of the CyberATDetect

A cyber incident detection module, CyberATDetect, will be developed as a component of MAIDS. The component will consist of multiple APIs (See Fig. 3) with the data flow being based on the state of the system. A management API will consume data from an Apache Kafka broker. There will then be a training and classifying API both of which will utilise a Spark cluster for machine learning. Spark was selected due to its high performance as a distributed stream processing system. It has high throughput when dealing with network data and compared to a similar performing competitor Samza it is less strict on its data requirements [11]. The combination of Spark and Kafka will allow for real-time classification of network flow data with high volumes of data and will enable the possibility of scaling the system up as required. The spark cluster will be running on the Hadoop platform and the system will utilise the benefits of the Hadoop File System (HDFS).

As aforementioned the data flow will be dependent on the state of the module (See Fig. 4). The module itself will be in one of two major states: harvesting and classifying. During the harvesting state, data will be ingested pre-processed and then stored within the HDFS. Once the component has harvested enough data the models can be trained, the details of which will be discussed in Sect. 3.2. The models will be based on three main ML algorithms, identified as strong performers on network traffic data from previous research.

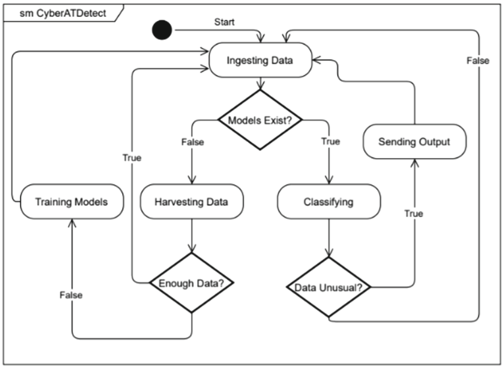

Fig. 4. State transition diagram of CyberATDetect

3.2 Cyber Detection with Machine Learning

Machine learning has become a necessity to secure modern networks. With the growing number of cyber threats and attack profiles, it is not possible to simply have a list of known attacks and their signatures. It has become a requirement to implement intelligent intrusion detection to fortify systems and their users. In S4AllCities this cyber incident detection module, within the MAIDS twin, will focus on identifying unusual traffic within the S4AllCities network. As specified in the architecture section three main algorithms will be selected for the CyberATDetect module itself, this will be based on research on their performance on various synthetic network traffic data. These will be strong performing algorithms that, when combined, should be able to identify a large variety of unusualness within the network traffic data, with a high degree of accuracy.

Network flow data has many features resulting in noise within the dataset and which limits the effectiveness of the machine learning algorithms and increases the time it takes them to be trained and classified [12]. Therefore, unimportant features must be removed in the pre-processing stage. These will be identified using feature-set selection. Once these are identified, the module should be able to preprocess this before storage to reduce training and classifying times.

When identifying strong performing algorithms there is not a single metric that will be looked at to rank these. A combination will be used, this is due to the various requirements of the CyberATDetect module itself and the balance of the datasets used for research. In the investigation many metrics were recorded, including area under the receiver operating characteristic (ROC) curve and Matthews Correlation Coefficient (MCC). The curve itself was also plotted giving a visual representation of the algorithm's performance.

The algorithms have been tested on multiple sources of data to ensure reliability. These are open datasets of synthetic network traffic data. The approach being used is to train using labelled data and to test the developed model on an unseen hold-out set, this was appropriate since all the datasets had many instances.

3.3 Discussion

The research will be expanded to investigate the classification of various attack types. This is not an area being focused on for the initial implementation due to the added complexity it may reduce the effectiveness of the system, hence it will be an additional feature on top of identifying unusualness. Overall cyber-security of the S4AllCities SoS is the priority, therefore it will be important to limit false negatives for readings as much as possible. In the event of a cyber-attack, it should be raised on the maximum number of occasions, although false positives can be disruptive if kept at a manageable rate it would be more tolerable than a high false-negative rate. Clustering will also be researched to aid with the classification of attack types, clustering may be useful to identify prominent features within the different types of attack. Clustering will also be useful if labelled data is not available, with the combining of multiple algorithms being a useful method of improving accuracy [13]. It will be important to identify algorithms with strengths in different areas to cover as many attack types as possible. With S4Allcities running pilots within multiple European cities: Trikala, Bilbao, and Pilsen, real network traffic quality data will become available. In this case, CyberATDetect CCRs will be scrutinised using such data. This data will also challenge the effectiveness of the S4AllCities SoS, as it will then be important to improve it in future versions, by the fall of 2022.

4 Physical Behavior Detection

The Physical behaviour detection module lays out within the MAIDS twin and approaches the detection of unusual behaviours in crowds using image analysis and computer vision techniques. Even though much progress has been made over the last decades, the task mentioned above remains a challenge due to several varying factors [14], such as camera field-of-view, crowd scale in video sequences, and cameras spatial resolution. As highlighted in the scientific literature, there are some analogies and similarities drawn between crowd behaviour, classical fluid dynamics and statistical mechanics of molecular gases [15].

Some crowd behaviour models are also inspired by cellular automata [16], which allow achieving good results in detecting macro-dynamics of crowds (macroscopic scale). Another popular model is the Social Force [17] that relies on a simple concept by which individuals in crowds move accordingly to certain constraints (environmental) and goals. Crowd Collectiveness was introduced to measure how individuals act as a group in motion [18]. Different from models inspired by hypothetical structures to understand crowd behaviour, some techniques learn patterns detecting semantic regions within crowded scenes[19]. Physical analogies using statistical mechanics principles have been successfully implemented to measure the crowd system's flow, energy and collectiveness using smart sensor observations and measurements for detecting crowd behaviour in context of urban spaces. In a way, the module of physical behaviour detection in S4AllCities represents an extension of an existing scientific method, which we set up in the last few years [20, 21].

Spatial crowd density allows to measure and represent crowd seeds. A set of key features can be defined for the crowd at various scales (micro, meso and macro). These features are chosen on purpose to characterize the state of crowd's dynamics being monitored and clustered, including for Individuals (micro-scale), Groups (meso-scale) and Whole Crowd (macro-scale). The method relies on entropy as a crowd analysis descriptor, and a crowd-space based on three features of Structure, Energy and Translation. In the next subsection, more details are given about the overall computer vision techniques to accomplish the task.

4.1 Physical Detection with Computer Vision

In this subsection, a more detailed description of the Physical Detection module is given. As briefly mentioned in the previous sections, Physical Behaviour Detection builds on the computation of some image features' entropy and works in a crowd -space defined on features of Energy, Structure and Translation as proposed in [21]. It is worth to spend some more words about the three features concerning different stages of crowds.

Structure represents the connection strength among individuals in crowd; Energy represent the level of excitation of crowd as a whole; Translation shows the motion of crowd.

The diagram in Fig. 5 shows some stages in crowd space. Point 1, represents a crowd state with zero connection strength, zero motion and no energy (it is not a likely state of crowd). To mention some more intuitive crowd states, point 5 coordinates have low energy, high translation and high structure such as a group of people on an elevator. Point 2, may represent the state of a group of bored spectators in a stadium (zero translation and energy and high structure). Point 7 may show the state of a sparse panicked crowd moving towards a direction (high Energy and Translation but zero Structure).

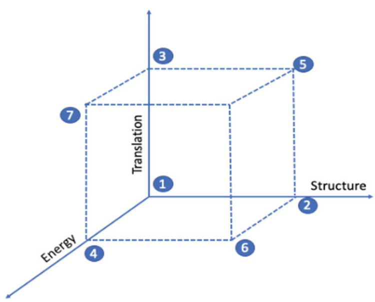

Fig. 5. Crowd space representations with Energy, Structure, Translation.

Structure, Energy and Translation are used as crowd density descriptors, which are mapped onto the statistical mechanics principles of entropy. An important assumption is that the crowd or the groups whose crowd is made of are considered homogeneous systems.

From the Information theory, the joint entropy of two ensembles X and Y is defined as in Eq. (1)

$$H(X,Y) = \sum_{xy \in A_X A_Y} P(x,y) \log \frac{1}{P(x,y)} \tag{1}$$

X and$Y$ are triples. $X = (x, A_x, \zeta_x)$ where x is a random variable from possible values in $A_x = \{a_1, a_2, \ldots, a_I\}$ with probabilities $\zeta_x = \{p_1, p_2, \ldots, p_I\}$. Y is a triple (y, Ay, ζ_y).

The entropy of a crowd [2] is defined as the joint entropy of N_p individuals who are scattered in N_l locations with a probability mass function f_{Y_i} on a discrete random variable, Y_i, defined at each spatial bin, l_i.

$$H(X_1, \ldots, X_{N_p}) = -\sum_{x_1 \in \zeta_x} \cdots \sum_{x_{N_p} \in \zeta_x} P(x_1, \ldots, x_{N_p}) \log P(x_1, \ldots, x_{N_p}) \tag{2}$$

Where X_k is a triple $(x_k, \zeta_X, \mathrm{P}_{X_k})$. x_k assume values out of the set $\zeta_X = \{l_1, l_2, \ldots l_{N_l}\}$, having probabilities $\mathrm{P}_{X_k} = \{p_{k,1}, p_{k,2}, \ldots p_{k,N_l}\}$, with $P(x_k = l_i) = p_{k,i}$.

Some assumptions are necessary to fully carry out all steps of the method [2]. The first one is to consider that a pattern is formed in the individuals in crowd. In this model, the locations of people are considered to be independent, and the individuals are considered to be identical.

The above-mentioned assumptions take to a more simplified computation of entropy as follows:

$$P(x = l_i) = \frac{n_i}{N_f N_p} \tag{3}$$

Where n_i is set as the sum of all density at bin l_i in N_f frames.

As briefly mentioned at the beginning of this section, some image features can be used to feed the Physical Behaviour Detection module. Corner features proposed in [22] well suit the purpose of the module because of their optimal performances on video tracking tasks. It is worth to notice that after detecting corners in frames, it is also necessary to remap them to locate the real-world locations and avoid the same side-effects previously discussed (distortions caused by projective transforms). More precisely, after remapping, the locations of corners are the internal positions of the features which are projected into the ground plane.

As noticeable in Fig. 6, individual positions extracted at t_0 are marked with red dots, while those at t_1 frame are marked in yellow. Individual positions can reveal crowd states because of different structure, translation and energy. In Fig. 4a, small variations in individual positions are detected with the lower size bin while they cannot be identified with the larger size bin. In Fig. 4b, it is noticed greater crowd translation, energy and low structure, having individuals moved faster and chaotically. Therefore, bin size needs to be fine-tuned over different real scenarios such as people on an escalator, spectator attending a concert or a football match. Some experiments are reported in [2]. In scenarios

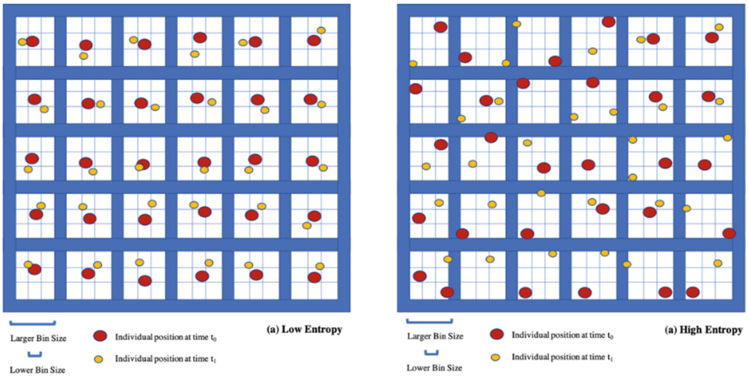

Fig. 6. Graphical Representation of two different crowd states (low and high entropy) analysed with a larger and a smaller bin size.

with crowds on escalators the best separation is achieved for bin sizes within the range [0.04 m, 0.2 m].

Before using entropy to compare behaviours between groups having different number of people, it is necessary to go through a normalisation step. For this purpose, specific entropy is defined as the entropy per unit of mass [21]. Furthermore, prior to the computation of entropy, three pre-processing steps are run on each frame as depicted in Fig. 7, below. The first pre-processing step deals with the distortion caused by the projective transform, which is due to the angle between the camera and scene plane. A head-height plane homography is applied to counterbalance the distortion side-effect. A calibration step is also considered for this purpose.

The second pre-processing step is the extraction of internal position density map. That is achieved by detecting each individual spatial coordinate within the crow. The computation of individual spatial coordinates is run over consecutive frames, which undergo a grid-based layout analysis defined by the bin size.

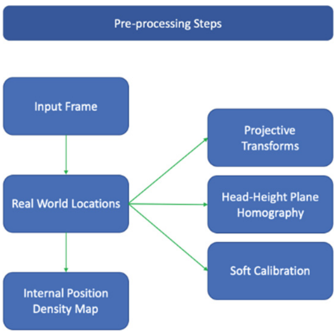

Fig. 7. Pre-processing applied on each frame

Other descriptors such as Collectiveness and Kinetic Energy are also compared to analyse macro-dynamics of crowd behaviour. Collectiveness seeks collective manifolds wherein consistent motion is observed in neighbourhoods, while Kinetic Energy of a crowd as a thermodynamic system is used as a measure of how excited the crowd is. In Fig. 8, below, Collectiveness and Kinetic Energy are employed and compared to run some tests over frames taken from a Stadium arena, at the Aneota Stadium, San Sebastian in Spain.

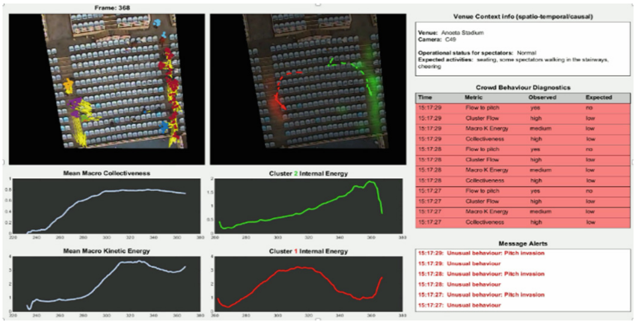

Fig. 8. Unusual behaviour is detected in the frame above [21]

5 Conclusion and Future Recommendations

This early work in the S4AllCities project sets the primary foundations for the development of the MAIDS Twin system. It specializes in cyber-physical behaviour detection of unusualness and understanding in context of urban smart spaces safety and security enforcement. The cyber behaviour detection module relies on achieving performing machine learning algorithms which not only detect unusualness in cyber traffic network, but also classify the type of threat or attack a smart space environment may endure. The classification of threats or attacks will be researcherd through investigating on quality data from the S$AllCities pilot cities using clustering methods for unsupervised learning. As for the physical behaviour detection module within MAIDS, we will exploit our described approach to investigate on the measurement and prediction of behaviour propagation in urban smart environment.

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Design of an IoT Architecture in Livestock Environments for the Treatment of Information for the Benefit of Cattle

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Abstract. Internet of things (IoT) is the interconnection of one or more technological devices with any other around it. The use of IoT in the livestock* sector helps in an advanced, simple and practical way by giving farmers the possibility of generating comments when making decisions, optimizing the growth and welfare of the animals, thus improving the agricultural production matrix. Several IoT architecture models allow the implementation of IoT on a large scale, two designs of architecture models will be denoted specifying and suggesting their use in livestock in our country. Having online information on animals is essential since the state of health, geo position, or location among others is revolutionizing the livestock business, thus turning the IoT market into a great ally of farmers, providing a future of great opportunities and improvement mentions. Basic criteria are detailed to lighten decision-making when choosing an IoT technology to be implemented. These criteria are developed after carrying out an analysis of documents, magazines, works, publications among others, identifying the needs in the development of livestock in rural areas of the province of Guayas.

Keywords: IoT · Interconnection · Technological devices · Evolve · Architecture · Network · Livestock

1 Introduction

The term Internet of Things (IoT) is a concept in which the virtual world of information technologies is integrated with the real world. It emerged in the early 2000s when the Auto-ID Center launched its idea of an automatic identification and tracking network of products within supply chains [1]. The application of technologies in the livestock sector has already been proven in other countries of development level obtaining great results such as the following: optimization of natural resources, the feasibility of operation and production to the farmer, improvement of product quality to the final consumer [2].

Livestock in Ecuador, based on the ESPAC - INEC report [3], found in 2018 that in the country there was a decreasing rate of annual variation of livestock in 0.007% evaluated with previous years (at the date there are no more reports of said entity), in that query it is that the Ecuadorian coast reached more than 40% of bovine production nationwide.

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It is the region of secondary importance; it also highlights that Guayas had over 7% of livestock [4]. Given these percentages, it can be noted that current production still maintains traditional mechanisms for livestock, so that adequate exploitation and profit maximization is not obtained, there is a general distrust towards farmers and therefore a low implementation of new technologies for improvement of development. of activities, processes, and generation of quality products.

There are studies carried out by several consulting firms that presage that this sector with IoT will generate income with an annual growth of 11% during its first 5 years after implementation. In this research, studies were carried out on architectures, platforms, and applications based on IoT that allow, according to their benefits, to improve the livestock sector of Guayas, specifically in rural areas, having as processes to improve the increase in the quality of the animal product, monitoring, and monitoring of both production and grazing, to reduce the mutilation and to reduce preventive health controls, avoiding unnecessary veterinary visits, which gives an optimization of resources. Taking advantage of the capabilities of identification, data acquisition, processing, and communication, IoT fully uses "objects" to offer services to all types of applications, while ensuring compliance with security and privacy requirements. (ITU-T Y.2060, 2012) [5].

2 Methods and Materials

For the development of this work, interpretive and descriptive research is carried out, with a qualitative approach, having a documentary design, as the main research method the bibliographic review of works related to the central theme was used, which helped to generate points of view, criteria, and approaches from various perspectives in grounding theories.

Currently, the ranchers of Ecuador work manually, that is, with manual data collection, field personnel who from time to time go through the stables monitoring their cattle. Likewise, there are different types of pests and epidemics that affect livestock giving losses of up to 35% in food production and large contamination in the production of meat and milk by the healthy state of the animals.

2.1 Bibliographic Review

The abstract vision of the Internet of Things Platforms is taken as the conjunction of three different systems: Edge corresponding to the sensor layer mainly, Cloud to the storage, computing and Cloud services, and Fog [6]. Different offers present in the world market, as well as academic articles, were investigated, and features of the technology that currently has a greater possibility of becoming a pioneer of IoT are detailed, among them we have Saas (Software as a Service), software as a service (Saas) allows users to connect cloud-based applications through the internet and can be used, it has a comprehensive software solution that is obtained from a cloud service provider paying for this service. [7] Iaas (Infrastructure as a Service) a computing infrastructure that manages and supplies over the internet, adjusts its services according to demand and pays for its use. Here you avoid the expense and administration of your physical servers and data center infrastructure. The user is responsible for managing, configuring, and installing software such as operating systems, middleware, and applications that work in the cloud. [8] and finally, Paas (Platform as a Service) is a service platform where the plug-in is developed and implemented in the cloud, from simple applications to business applications developed in the cloud. This works in the same way as Saas, you buy the resource you need from the cloud service provider, paying only for the use you make [8].

2.2 Applications of IoT in the Livestock Sector

Management and Use of Drones for Grazing Control - currently the use of drones is being more common than we can think, having better control of the cattle in the aspect of feeding, health among other things, and therefore will have a better product quality for sale by the consumer.

Use of Robotics - for milk production with the application of robots for milk processing, milking is optimized, currently, there are new robotic implements that can develop a data capture and management file such as origin, age, health status, type of milk quality among others.

Chip Implementation - in livestock it has several uses of very significant value among them its geolocation, the capture of health behavior, and reproduction stage. In the health aspect, data can be obtained for temperature measurement, reactions to foods or medical supplements, identification of any type of pests or insects, and control. of vaccines that lead the farmer to take preventive and corrective measures in the health status of the cattle, thus avoiding losses or infections due to diseases. In the aspect of reproduction, the moment of the heat of the animals can be identified given their production of hormones and with this mating can be planned, thus leading to a correct administration and control of the offspring.

2.3 Comparison of IoT Architecture Models

This document is based on 2 in the design of two architectural models, one based on components and the other based on layers. The component model is more generalist than the layer-based one, but this does not mean that the capabilities with which the platforms should be equipped are lost. Due to its greater simplicity in functional components, it is concluded that the component architecture model is the one that more generally encompasses the interconnection modules from which the IoT platforms must be formed. Both architectures can be connected with the idealization of the IoT in Edge, Fog, and Cloud systems, although their relationship is not always direct [9].

2.4 Layer Based IoT Architecture Design Applicable in Livestock

For the implementation and development of the Internet of Things, the best scenario is idealized by systems composed of three subsystems, two of them marked: Edge, Fog, and Cloud. Of these subsystems we can define the following criteria or concepts [10]:

Cloud: It is known as "The Cloud" and it is a subsystem in which the data is found on the network on different platforms that allow its access from anywhere and in real-time.

Edge: This subsystem works by collecting, processing, and treating data in a network of devices with sensors and actuators.

Fog: This subsystem is intended to act as a bridge between the Edge and Cloud subsystems, it is a technological infrastructure that is closer to devices or data sources.

Regardless of where the implemented devices are located and whether or not they are near other devices, the platforms will allow centralized control of them and will function as a data processing unit. A first approximation of the architecture of an IoT platform is made up of five layers, described below [11]:

Perception Layer: Allows the collection of information about "things" through sensors.

Transport Layer: This allows the sending of the data collected in the perception layer to the processing layer.

Processing Layer: It allows the treatment and storage of the data previously collected by the sensors.

Application Layer: Allows the visualization and use of the processed data and varies depending on the requirements of the use that end-users need.

Business Layer: Allows the monetization of the applications of the previous layer.

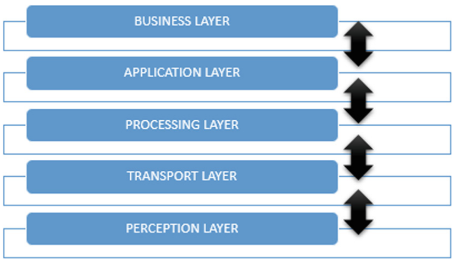

Fig. 1. First model IoT architecture. Layer-based model.

2.5 Component-Based IoT Architecture Design Applicable in Livestock

Regardless of where the implemented devices are located and whether or not they are near other devices, the platforms will allow centralized control of them and will function as a data processing unit. Another architecture design proposal can be detailed how the parts that make up the architecture of IoT platforms are simplified into four components, according to their functionality (Fig. 1):

1. Sensors 2. Identification and communication 3. Computing and cloud 4. Services and applications

This scheme presents the distribution and interaction between the components that make up this architecture of IoT platforms (Fig. 2).

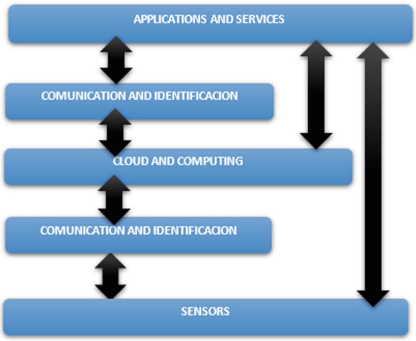

Fig. 2. Second model IoT architecture. Component-based model.

2.6 Operation of Architectures in IoT Technology

Both models can work on the most used IoT technology such as LPWA technology: Lora and NB-En, the works of researched authors offer an exhaustive review on NB-IoT and LoRa as efficient solutions to connect devices. Unlicensed LoRa is shown to have advantages in terms of battery life, capacity, and cost. Meanwhile, the NB-IoT license offers benefits in terms of QoS, latency, reliability, and range [12]. A 2017 comparative study of LPWAN technologies for large-scale IoT implementation [12], predicted that by 2020, more than 50 billion devices will be connected through radio communications. Along with the rapid growth of the Internet of Things (IoT) market, Low Power Wide Area Networks (LPWAN) have become a popular low-rate, long-range radio communication technology. The authors show that Sigfox and LoRa are advantageous in terms of battery life, capacity and cost. Meanwhile, NB-IoT offers benefits in terms of latency and quality of service. Also, we analyze the IoT success factors of these LPWAN technologies [13]. Animal monitoring based on IoT technologies was also consulted [14]. Placing grazing animals in vineyards is a technique to keep them free of pests. However, it requires additional support for animal husbandry activities. According to this, it will depend on each farmer under which LPWAN technology will want to implement the IoT architecture models.

Due to its greater simplicity in functional components, it is concluded that the second architecture model is the one that encompasses in a more general way the modules from which the IoT platforms must be formed. Both architectures can be connected to the LPWAN technology with the idealization of the IoT in Edge, Fog, and Cloud systems, although their relationship is not always direct. At present, there are several connectivity technologies where these models can be applied, such as this knowledge: 6LoWPAN, Bluetooth, Ethernet, LR-WPAN (IEEE 802.15.4), LoRa, NB-IoT, NFC, RFID, Sigfox, Thread, Wi-Fi, Wireless HART, ZigBee, Z-Wave.

3 Research Results Based on IoT Architecture Component Model

Capacity. In this section we will talk about the peak speeds that can be reached with the four most important LPWAN technologies, and if there is any type of limitation in the sending of information. In the first room, the maximum possible speeds for the ascending and descending directions of communication will be displayed (Table 1).

Table 1. Capacity IoT technologies based in component model.

	Downward communication	Upward communication
NB-IoT	250 kbps	250 kbps
LTE-M	1 Mbps	1 Mbps
Sigfox	600 bps	100 bps
LoRaWAN	50 kbps	50 kbps

Limitation on the Number of Messages Sent. About the limits on sending information, as can be seen in Sigfox's pricing plans, in which there is a maximum number of messages to send. LoRaWAN will also be able to work in bands with a 10% duty cycle.

NB-IoT and LTE-M do not a priori have a cap on the amount of information or time that it can be in the air. The conditions will depend on the type of contract signed with the mobile operators given the bandwidth capacity (Table 2)

Table 2. Limitation of messages in IoT technologies.

	Limitation of messages
NB-IoT	No
LTE-M	No
Sigfox	Yes
LoRaWAN	Yes

Coverage. The estimated range is identified in two different ways. In terms of maximum compensable attenuation, an objective parameter and easily calculable from the system specifications; and in length, somewhat more imprecise as it depends on the environment and communication lines of sight (Table 3).

Table 3. Coverage in IoT technologies based in component model.

	Frequency	Urban distance	Rural distance
NB-IoT	164 dB		15 km
LTE-M	155 dB		15 km
Sigfox	158 dB	3–10 km	20–50 km
LoRaWAN	157 dB	2–5 km	10–15 km

Energy Consumption. Energy consumption. For a 5WH reference battery, all the technologies to be studied are designed for an average life of 10 years. Despite the difficulty in finding experimentally justified consumption values, in [15] a study on the efficiency of NB-IoT, Sigfox, and LoRaWAN in different coverage environments can be found. Thus, three study values are taken as an example located in a coverage range of around 150 dB of compensable attenuation, defining the emission power and the hardware used. The consensus is that LoRaWAN and Sigfox have better efficiency than the technologies that come from LTE. This can translate into a power-loss sending and receiving signaling against the asynchronous protocols of LoRaWAN and Sigfox. Faced with this lack of information, better performance of Sigfox and LoRaWAN will be assumed in this work compared to NB-IoT and LTE-M. The fact of presenting the source [15] is carried out on the occasion of observing this section of IoT technologies, as it contradicts what is commonly expressed (Table 4).

Table 4. Energy consumption in IoT technologies based on component model.

	Energy consumption (sent 12 Bytes)
NB-IoT – Quectel BC95 B8, TX 23dBm, LB 154 dB	7,74 mW/byte
Sigfox – Chipset STM S2-LP, TX 14 dBm, LB 154 dB	33 mW/byte
LoRaWAN – Acsip S75S incl. 0 repetitions, TX 14 dBm, LB 151 dB	15,47 mW/byte

4 Conclusion and Suggestions

For various reasons, the agricultural sector has not yet assessed the potential of the use of currently available technologies and lessen its impact on productivity and financial management. The combination of these factors determines that at the moment there are few cases of success in the livestock of Ecuador, not having reached a critical mass of innovators that allows generating a leap in adoption and with-it great visibility in the live-stock market compared to other countries. Certain advantages can be seen when adopting this type of technology, such as Daily updates on the status and location of the herd, herd management decisions based on data, the significant increase in the number of weaned calves, early warning of theft directly to the farmer's smartphone, it will not incur in cellular coverage to manage certain data, robustness capable of withstanding field conditions.

During the development of this work, various technologies of the livestock sector have been demonstrated that will help the producer to add value when making decisions, in line with the objectives that he wishes to achieve within his planning.

Accurate information will allow the livestock producer to act proactively on his herd, and more specifically, on the animals that show a deviation from optimal performance. This is happening in other parts of the world, and it will soon begin to do so in our country. The only thing missing is to be able to take the leap so that producers know it, trust the product and start implementing it. For the latter to happen, new companies that offer the producer the information al-ready processed at their fingertips must emerge. In doing so, many fears of the producer will be mitigated, and the barriers that will allow the acceleration of a change that will be exponential will be eliminated.

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Intelligent Computing and Cognitive Computing in Healthcare

Requirements Analysis on Emotional Preferences for Leisure Activities in Virtual Reality for Female Nursing Home Residents – A Mixed Method Approach

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Abstract. Insufficient tailoring of individual needs of nursing home residents can lead to standardized (leisure) activities. Virtual Reality (VR) provides the potential to offer a multimodal experience of individualized activities to residents. The aim of the VR4Care study is to explore attitudes, knowledge, and expectations regarding the use of VR glasses for (leisure) activities in female residents living in rural nursing homes. A mixed method approach in two phases (phase 1: interviews with a complementary standardized questionnaire; phase 2: measurement of affective states) was used. In total, 20 participants were interviewed regarding nine categories. The results show that the most described VR-scenarios for (leisure) activities include arts and crafts (e.g., sewing and knitting), followed by gardening (e.g., farmhouse garden), washing and ironing clothes and dancing (e.g., Austrian folk dances). This study serves as an important basis for scenario development and for testing the use of biosensor measurements in phase 2.

Keywords: Virtual reality · Emotional preferences · Leisure activities

1 Background

Demographic change is causing an increase in older people [1] and consequently raises the need for health services. This leads to the fact that more and more nursing home beds will be needed in the future [2]. In contrast to the increasing number of (older) people, there is a widening supply gap of nurses in all care settings [3].

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Regarding nursing home settings, a lack of health care professionals, nursing care time and other lack of resources can lead to (leisure) activities for residents being standardized because they are not sufficiently tailored to individual needs [4]. Virtual reality (VR) has the potential to support nursing and other health care professions [5, 6] to offer individualized (leisure) activities to residents.

The aim of this study is to explore attitudes, knowledge, and expectations regarding the use of VR glasses for (leisure) activities in female residents living in rural nursing homes.

2 Methods

2.1 Design

This study used a mixed method approach in two phases. In the first phase, qualitative interviews were conducted with a complementary questionnaire to determine (leisure) activities that people used to do, that they currently enjoy doing and that they would like to do in the future. In the second phase, the study will focus on the measurement of affective states of residents with respect to their VR-based experience of various activities that will be pre-selected based on the results of the first phase. Measurements will be conducted using VR built-in eye tracking and wearable biosensors for electro-dermal, electro-cardiac and facial electro-myographic sensing.

2.2 Setting and Sample

The study was conducted in a rural nursing home in Austria. A total of 13 female nursing home residents, five nurses, one dementia trainer and one occupational therapist participated in this study. A convenience sampling was chosen as a sampling strategy. The nursing director recruited the dementia trainer and the nurses, and the included nurses recruited the nursing home residents. The occupational therapist was recruited by the Medical University of Graz.

The ethical approval was obtained from the Ethics Committee of the Medical University of Graz (1567/2019). The participants were informed verbally and in writing about the study and gave their written consent to participate.

2.3 Data Collection

Phase 1: Focus groups (n = 3) and individual interviews (n = 5) were conducted with the participants. In addition, characteristics of the sample were gathered by means of quantitative standardized questions and a complementary questionnaire [7] was applied to determine (leisure) activities that people used to do, that they currently enjoy doing and that they would like to do in the future. The interviews were held by one researcher in February 2020. An interview guide was used to conduct the interviews. It was structured into introductory, transition, key, final and summary questions. To avoid ambiguities, the interviewer summarized the main statements again at the end of the interview. There was an opportunity for clarification and further comments [8]. All interviews were audio-recorded with a smartphone or tablet. Then they were transcribed verbatim by an external transcription office and organized with MAXQDA Pro Analytics software.

Phase 2: This phase of the study will focus on the measurement of affective states of residents with respect to their VR-based experience of various activities that will be pre-selected based on the results of the first phase. Measurements will be conducted using VR built-in eye tracking and wearable biosensors for electro-dermal, electro-cardiac and facial electro-myographic sensing.

2.4 Data Analysis:

Phase 1: A qualitative content analysis [8, 9] was carried out using a deductive and inductive coding frame. The coding framework was developed by two researchers and consisted of main categories which were defined deductively based on the interview guide, and sub-categories which were defined inductively based on the data and which represent the dimensions of the categories. The software MAXQDA Pro Analytics was used to support the data analyses.

Phase 2: The research plan foresees a substantiation of users' preferences with regard to the visual content, e.g., the definition of 'areas of interest' (AOIs) within the VR-based experience of the 360° videos. The VR headsets are equipped with eye tracking to identify users' fixation points as well as their eye movements regarding the presented video content, which will provide the basis for the analysis of selective attention. Those time intervals in which the user was attending to specific AOIs will be synchronized with the results of the biosensor-based emotion analysis. We will assign an emotional weight to the AOIs from the synchronization of these two data streams and conclude with a statistical analysis of the overall distribution of emotional attribution to specific categories of visual content, such as favorite places, favorite architecture, objects in nature, and so forth. As an expected result, we will receive a statistically weighted emotional preference to specific AOIs in terms of a computational user experience. This phase will be carried out in future steps of the project.

3 Results

3.1 Basic Characteristics

The 13 nursing home residents were on average to a limited extent care dependent. The five included nurses were on average 37 years old and predominantly female. The participating occupational therapist was 38 years and the dementia trainer 55 years old. The results from the used (leisure) activity questionnaire [7] show that gardening (100%), followed by cooking and baking (92.3%), laundry and ironing (84.6%), arts and crafts, and reading (both 76.9%) were among the most popular (leisure) activities.

3.2 Knowledge and Attitudes

Results from the interviews show that most participants have had no experience with VR, but the attitudes of all participants regarding the use of VR in nursing practice are predominantly positive. When asked about attitudes/feelings, one participant responded, *"Curiosity, actually! Fascinating, I would test it right away. Yes, I would! (…) I have no concerns."*

3.3 (Leisure) Activities Expectations

A total of 9 categories were surveyed during the interviews. In these interviews, the participants described detailed scenarios that they would like to experience in virtual reality, including the sensory impressions which they would like to experience.

For *health and fitness*, women mentioned cycling most often, followed by swimming and running/jogging. Women would like to **cycle** on a flat cycle path with little traffic on a beautiful spring day in the area where they grew up. They would like to enjoy the landscape, see and smell flowers and hear typical environmental sounds such as cars. In this scenario, they would like to cycle actively and not watch other people. Regarding the (leisure) activity **swimming**, women want to experience this scenario actively in a local lake or pond with a few (maximum 10 people) people in the water. It is important that they only swim and do not dive, as they also want to see the landscape with meadows and trees and hear the birds in the background. Furthermore, the participants described that they would like to feel the water, the stones and even fishes. In view of **running/jogging**, women would like to do that in rural areas on meadows or in forests in the immediate vicinity of where they grew up. While running/jogging they would like to see and hear animals such as birds and smell the grass. Furthermore, they want to experience this activity both actively and passively, which means that they actively run/jog a bit themselves, then take a break on a bench and watch other people running/jogging.

The most popular *sports* activities include skiing, tennis, and bowling. Women would love to **ski** in Austria's well-known ski resorts, like Schladming, on a flat slope on a beautiful winter day. They would also like to watch other skiers on the slope and enjoy the view. In the background they would like to hear the snow and the sound of skiers. They would like to experience the whole scenario actively. **Tennis** was mentioned as another (leisure) activity in this category. Here, the participants would like to enjoy the scenario only passively, sitting in the stands and watching other people play tennis (e.g., at a tournament). The game is played on a clay court and all you hear is people cheering in the background and the tennis balls. In terms of **bowling**, women want to play actively in this scenario. The bowling alley is in an inn in a rural village. The game is played in teams of two. In the background you can hear the typical ambient sounds of a bowling alley, and the scores are recorded on a board on the wall.

In the category of *creativity*, arts and crafts were mentioned most frequently, followed by singing. The only (leisure) activity that was described by all participants was **arts and crafts**. This includes knitting and sewing. For the VR scenario, a total of two places were described where they would like to experience this: on the one hand, their own (sewing) room with an old sewing machine with a foot treadle, or, on the other hand, a traditional farmhouse kitchen with them sitting on a corner bench next to a masonry heater. Traditional Austrian dresses, such as "Dirndl", or skirts are sewn, and pullovers, waistcoats and socks are knitted. The sewing machine or the radio can be heard in the background and the participants would like to feel the fabric or the wool. All scenarios are to be experienced from an active point of view. The second most frequently described (leisure) activity was **singing**. Women would like to experience the scenario in VR in a church in a choir or at home in the living room with a folk music group, both actively as a singer and/or passively as a spectator. Singing would be either related to church hymns, Christmas carols or classical Austrian folk songs.

The most stated *household activities* include cooking, baking, and making own beverages, as well as gardening, doing laundry and ironing. The participants would like to **cook or bake** in a modern kitchen. They would like to experience the preparation of a dish from an active point of view. Either savory dishes such as Austria's famous "Wiener Schnitzel" or desserts such as "Kaiserschmarrn" are cooked, and pastries or bread are baked. Furthermore, the participants used to make homemade **beverages**, such as fruit juices and cordials. In the background you can hear the radio and the typical sounds of a kitchen. The nursing home residents want to smell, taste, and feel what they are cooking/baking in the VR scenario. **Working in the garden** is another (leisure) activity that women would like to experience. The majority would like to do gardening from an active point of view. Very often the example of a rose garden is described, in which the participants like to cut and replant flowers (such as roses). Nevertheless, there should also be passive elements, such as simply standing in the garden and looking at the flowers. It is important that typical environmental sounds, such as birds or flower clippers or swings, can be heard. The activity of doing **laundry and ironing** was mentioned frequently, but no detailed descriptions were given. Women would like to wash the laundry in a washing machine and then hang it up on a clothesline in the garden. The laundry is then ironed in the living room. Either the radio or the television is heard in the background. The participants would like to experience this scenario actively.

(Leisure) activities outside the home area include walking and hiking as the most popular activities they would like to experience in VR scenarios. The female nursing home residents would like to either **walk** through a forest and then across meadows or **hike** on a mountain/alpine pasture, perceiving the surrounding sounds and perhaps looking for mushrooms or flowers/herbs while doing so. This also reflects what they would like to perceive with their senses, such as seeing a panoramic view or hiking/alpine paths and hearing animals like birds or cows.

Stated *(leisure) activities inside the house* were mainly reading, listening to music/the radio or card games. For the (leisure) activity **reading and listening to music/the radio**, the described scenarios were very similar. The participants would like to sit in a TV chair in the living room and either read a book or listen to music/the radio. No wishes were expressed about which books to read, but in terms of music they would like to listen to traditional Austrian folk music. The scenario can be experienced both actively and passively. The most popular **card game** that female nursing home residents would like to play is "Schnapsen"/"Sixty-six". This VR scenario should be experienced actively at home, either in the kitchen or in the living room. The game is played with French-suited playing cards, and you can hear folk music and see drinks (wine, beer, or fruit juices) on the table. In addition, the participants want to feel the playing cards.

For *social activities*, family visits were mentioned most often. The female nursing home residents would like to meet and talk to their families (siblings, children, grandchildren, and great-grandchildren) at home, either in the house where the participants grew up or in the nursing home where they are currently living. Everyone sits together and drinks coffee and eats biscuits or cake. They would like to experience this scenario from an active point of view and not sit by as spectators.

In the field of *education*, hardly any VR scenarios were described by female nursing home residents. Either the participants read a book or watch a documentary on TV about History (Greeks, Romans, …). However, no more details were given by the participants.

In the area of *excursions, travel & entertainment*, dancing, and travelling/holidays were described very frequently. **Dancing** is one of the most favorite (leisure) activities. Almost all participants describe some scenario in which they would like to dance. The places where the dancing takes place range from a garden during a summer party to a (large) hall of an inn. Furthermore, a long list of dances which they would like to dance or see was obtained, ranging from Viennese waltz to polka. The activity levels for the scenario are both active and passive. The participants would like to stand on the edge of the dance floor and watch other people dance before they dance on the dance floor themselves. In the background you can hear people talking and the music being danced to, and you can also smell food (e.g., Wiener Schnitzel) and drinks (wine or non-alcoholic beverages). In terms of **travelling/holidays**, the female nursing home residents would like to go on holiday in Austria or in neighboring countries, such as Italy or Croatia. In Austria, they would like to take city trips, for example to Vienna or Salzburg, and go sightseeing. Abroad, they would like to go on a seaside holiday. They would like to walk on the beach or the promenade, enjoy a beautiful summer day by the sea, listening to the waves and seagulls.

4 Discussion

This study focuses on female nursing home residents' knowledge and attitudes regarding virtual reality and which (leisure) activities they would like to experience in VR.

While knowledge about VR was very low among almost all participants, attitudes were very positive, which is consistent with the current state of research [10].

With regard to (leisure) activities, most VR scenarios were described in the categories of creativity, followed by household activities and excursion, travel and entertainment. The (leisure) activity of arts and crafts in the category *creativity* was described by all participants and therefore seems to be a very important and popular form of (leisure) activity for women. This activity is so popular that the qualitative study by Liddle et al. [11] addressed the question of why arts and crafts are so popular among older women. The authors' possible reasoning was that by participating in art and craft activities, older women find meaning in their lives and contribute to their subjective well-being while helping and being valued by others.

Travelling was also mentioned several times. One possible explanation might be that many participants grew up in poor conditions, especially the rural population, and very rarely had the opportunity to go on holiday. Most of their lives consisted of hard physical work on a farm, and when they did have the opportunity to go on holiday, it was often only for a few days [11]. Some participants would like to relive those beautiful memories, such as walking on the beach, and others would like to fulfill a dream in the virtual world [12].

Cycling, going for a walk and swimming were further popular (leisure) activities mentioned by the study participants. These results are confirmed by quantitative studies that measured the physical activities of persons >50 years in the USA [13], Switzerland [14] or Poland [15] for both men and women. Reasons for this popularity could be that, on the one hand, these leisure activities are so-called classical activities (e.g., the first cycle was invented in 1817) and they are easy to do because they need hardly any equipment and are in general affordable, and that, on the other hand, these leisure activities were also popular means of transportation [16].

In many descriptions of the potential VR scenarios, nature, farm animals, and the house where the participants grew up play a big role. One reason could be that they spent their most formative phases (childhood and puberty) in the countryside on a farm with lots of farm animals and that this is a familiar environment for the participants which gives them security and a sense of well-being. According to the literature, information such as favorite places, favorite animals or favorite sounds should be collected and integrated into VR scenarios, so that individual events can be relived and, in addition, this can counteract the feeling of loneliness and subsequently also depression [12]. Especially animals have a positive effect on physical and mental health. Thus, blood pressure, heart rate and symptoms of depression and anxiety are reduced and a faster recovery from mental stress is achieved [17].

Study limitation: Only female participants from the rural area were included in the study.

5 Conclusion

The study shows that the most described VR-scenarios for (leisure) activities include arts and crafts, especially sewing and knitting, followed by gardening, washing and ironing clothes and dancing.

These results serve as an important basis for VR-scenario development and testing the use of biosensor measurements in the subsequent phase 2 of this study. Both phases of the study will be used in the future to design VR-based services for nursing home residents that are particularly suited to provide optimized, individually tailored and emotionally activating experiences for nursing home residents. Further research should include nursing home residents from urban areas.

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Virtual Reality-Based Sensory Triggers and Gaze-Based Estimation for Mental Health Care

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Abstract. Recent studies underline the importance of the cognitive reserve for mental health, especially in dementia care, which is supported by stress reduction, joyful experience and meditation. Mindfulness training has previously been successfully applied to dementia and indicates a lasting positive effect on cognitive reserve, well-being and motivation [1.Clin. Psychol. Rev. 31:449–464]. We investigated the potential of unobtrusive technology for the measurement of eye movements in Virtual Reality (VR)-based mindfulness training. The objective of this research is to develop software estimators for cognitive assessment and mindfulness trait in order to apply VR technology in the future as a screening instrument, monitoring tool and thereby serving for decision support in mental health care. Eye movement analysis within a pilot study demonstrated significantly different results for persons with Alzheimer's dementia and healthy controls. These results indicate that significant conclusions are drawn on relevant mental health parameters even within a very short eye movement measurement period applying few minutes of observation of carefully selected video-based stimuli.

Keywords: Virtual Reality · Eye movement analysis · Mental health care

1 Introduction

Mindfulness training has been successfully applied to persons with dementia (PwD) and results indicate a lasting positive effect on the cognitive reserve, well-being and motivation [1]. RCT studies that were performed with adult persons with mild cognitive impairments (MCI) as well as with persons with subjective cognitive decline (SCD) demonstrate that mindfulness training provides significant improvements in selective & executive attention, memory and depressive symptoms [2].

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(a)  (b)

Fig. 1. VR-based mindfulness training and assessment using eye movement feature analysis. (a) Persons with dementia from a nursing home as well as healthy control persons were participating in the VR-based mindfulness training. (b) Sensory triggers, such as, videos but also 3D computer graphics were presented to the participants for free observation. The image depicts a smooth pursuit challenge, i.e., to continuously track the position of the butterfly with her eyes. The eye gaze on the scene that was captured at a time instant is represented by a red circle.

We investigated the potential of unobtrusive eye movement measurement technology in Virtual Reality (VR)-based mindfulness training. The objective of this research is to develop software estimators for cognitive assessment and mindfulness trait in order to apply VR technology in the future as a screening instrument, monitoring tool and thereby serving for decision support in mental health care.

We applied VR-based intervention and assessment for dementia care in an exploratory pilot study (see Fig. 1). VR-based intervention to foster mindfulness and joyful as well as relaxed sensory activation was applied to PwD with Alzheimer's dementia (AD) and healthy controls using 30 min of panoramic video-based multi-sensory experiences. The intervention presented stimuli that empower relaxation (body-scanning, beach, forest) and activation (bakery, orchestra). Body scanning was applied with a video in which a Feldenkrais trainer recommended on how to mindfully focus on body parts. EEG-based analysis associated with relaxation and inhibitory control were recorded before, during and after intervention and eye tracking was applied during intervention. EEG analysis showed significant increases in alpha power and brain connectivity for PwD with AD and controls as described in [3].

Eye movement analysis demonstrated significant differences between PwD (AD) and controls with respect to the eye blink rate from the observation of a 3 min video, as well as significant correlations between eye movements and the Freiburg Mindfulness Inventory score. The eye blink rate during a smooth pursuit task correlated with the Mini-Mental State Exam (MMSE). These results indicate that even in a very short measurement period of 3 min observation with simple video-based stimuli one can draw significant conclusions on relevant mental health parameters.

The VR-study demonstrated significant proof that mental health state and mindfulness trait could be measured during the intervention. This indicates huge potential for non-invasive assessment and decision support. The described VR-based intervention component anticipates numerous opportunities for novel VR-based care services for measuring during empowering cognitive reserve, inducing sensory activation, raising awareness and motivation for self-regulation, and as pervasive assessment tool [3].

2 Context and Related Work

Dementia is a broad category of neurocognitive disorders that cause a long term and gradual decrease in the ability to think and remember. It affects a person's independent daily functioning and leads to many negative outcomes, like anxiety, depression, language problems and an increase of apathy. In the course of dementia the majority of affected persons develops behavioral and psychological symptoms (BPSD) [4]. A dementia diagnosis causes a significant change in a person's daily functioning. A person's usual mental functioning shows a greater decline than one would expect due to aging. The disease is also a great burden for caregivers. 50 million people now have dementia worldwide, a number which is expected to increase to 76 million by 2030 [5]. Prevalence and incidence dramatically raise beyond the age of 60. Dementia rates burden global health care resources to a serious degree. The annual costs for dementia, for example, in Austria are estimated to be 2.9 billion Euro. In home related treatment the costs are estimated about 10.000 € per person and significantly higher in stationary environments (25.000 €–43.000 €). In contrast to increasing dementia rates the number of available caregivers is significantly decreasing [6].

Mindfulness is an integrative, mind-body based approach that helps people to change the way they think and feel about their (stressful) experiences. This becomes especially relevant when chronic illnesses and psychological problems occur in the course of life. A review by Piersol et al. [7] shows that mindfulness training for caregivers leads to an improvement in mental health and reduces the burden of care.

Mindfulness based intervention (MBI) has resulted in several concrete improvements for outcome measures. Chiesa [1] suggested from reviewed studies that mindfulness training could be associated with significant improvements in selective & executive attention in adults. Quintana-Hernandez [8] presented an LRCT study including $N = 120$ patients with AD that were involved for 2 years in a mindfulness stress reduction (MBSR [1]) oriented intervention. The MBSR group showed better cognitive scores with the conclusion that mindfulness can be used as a non-pharmacological treatment. The impact of mindfulness based stress reduction on persons with MCI and SCD is presented in Berk [2]. RCT studies reported for persons with MCI that MBI resulted in less memory deterioration and reduced more depressive symptoms compared to the control group; for SCD the MBI group improved on measures of depression, and anxiety, and attention regulation was improved.

The benefit of VR-based interventions for BPSD was recently demonstrated in several RCT studies. D'Cunha et al. [9] provided a review on various study designs on

VR-based interventions that promote well-being for people living with dementia and MCI confirming VR as a novel and emerging method that may provide cognitive stimulation and improve well-being. More studies on apathy, quality of life, and depressive symptoms were suggested with the incorporation of physiological biomarker outcomes. Clay et al. [10] demonstrated results about immersive VR in the assessment and treatment of AD that there are no reported issues with VR tolerability in participants and high accuracy in differentiating participants with AD from controls. Thapa et al. [11] provided evidence in an RCT study with 68 persons with MCI (VR intervention with game-based content) for significantly improved executive functions (attention, memory and processing speed) and brain function in the resting state.

This work presents a combination of mindfulness and VR-based training approaches. Navarro-Haro systematically applied in a pilot study [12] VR-based mindfulness training in the context of mental disorders and evaluated a combined non-VR & VR-based MBI strategy for the treatment of generalized anxiety disorder (GAD). The results demonstrated that anxious patients are much more willing to seek treatment delivered via therapists together with VR compared to traditional therapy with no VR, and added preliminary effectiveness of a MBI to treat GAD symptoms, depression, anxiety, and emotion dysregulation to previous non-VR oriented results.

We conclude that mindfulness can be applied as a non-pharmacological treatment. There is a huge potential for meaningful, very well accepted interventions, arising from feedback from the patients as well as from the findings in the study's assessments. Immersive VR-based technology serves as a basis for the development of a product for the beneficial impact on BPSD, such as, for stress and anxiety reduction as well as for inducing positive effects on executive function performance.

3 Eye Movement Analysis in VR-Based Environments

Progressive neurological diseases like AD are known for the decreasing functional performance in eye movement behavior [13]. Crawford et al. [14] has identified by anti-saccade tests that AD patients are characterized by a significant impairment of inhibitory functionality which can be measured using eye movements. The anti-saccade (AS) task requires from the test person a voluntary turning away from an actual stimulus and analyzes eye movement behavior further (Wilcockson et al. [15]). [16] applied a pervasive measurement paradigm using a Tablet-based camera within a serious game framework to determine the degree of dementia.

Clay et al. [17] provided an introduction into the field of eye tracking in VR. VR offers a lab environment with high immersion and close alignment with reality. An experiment using VR takes place in a highly controlled environment and allows for a more in-depth amount of information to be gathered about the actions of a subject. The most related work is by Kumari et al. [18] who concluded that cultivated but not dispositional mindfulness is associated with improved attention and sensorimotor control as indexed by SPEM (smooth pursuit) and AS tasks.

To the best of our knowledge, our presented work extends current state-of-the-art in this field by identifying features of VR-based eye movements that discriminate persons with dementia from healthy control based on simple video-based stimuli and a single playful smooth pursuit-based task. Furthermore, traits of mindfulness are correlated with eye movements and as well related to dementia detection.

4 Experimental Results

We applied VR-based intervention and assessment for dementia care in a proof-of-concept study. VR-based intervention was applied with the objective to foster mindfulness and sensory activation. Participants of the study were PwD with AD (n = 12, age M = 85.0 years, MMSE M = 21.5) as well as healthy controls (n = 12, age M = 75.1 years, MMSE M = 30). The VR-based intervention consisted of a panoramic video-based multi-sensory experience with a duration of 30 min in total. The study was approved by the Ethics Committee of the Medical University of Graz, Austria (reference number EK Nr. 1313/2019) and is in accordance with the ethical standards of the Declaration of Helsinki.

For stimulus presentation we used the VR headset package including HTC Vive headset (resolution 2160 x 1200 Pixel, frame display rate 45 Hz) and Tobii-based eye tracking. The gaze data output frequency (binocular) was 120 Hz, with an estimated accuracy of gaze by 0.5°. A five point calibration procedure was applied. The trackable field of view was 110°, i.e., the full HTC Vive field of view. The number of IR illuminators was 10 per eye and each eye was tracked separately. The latency in the VR presentation was approximately 10 ms (time from mid exposure to data available on client interface). The 3D engine compatibility was used to compute eye movement features with Unity. The interface to the Tobii Pro SDK was used to track data output in real-time. The tracking technique was binocular dark pupil tracking. The data output for each eye was, as follows, timestamp (device and system), gaze origin, gaze direction, pupil position, and absolute pupil size. From the raw data we estimated fixations (based on [20]), saccades, blink, fixation and saccade rate.

The intervention presented stimuli (see Fig. 2) that empower relaxation (body-scanning, beach, forest) and activation (bakery, orchestra). The sequence of the stimuli was motivated by the mindfulness program manual for people with dementia by Chan et al. [19]. The intervention was designed with a sequence of panoramic videos, starting with the Body Scan video of a Feldenkrais trainer motivating to perform exercises, further relaxing beach and forest sceneries, pleasurable food consumption scenes (bread, pudding), a video with dog puppies, orchestra presentation and a butterfly in a meadow. In selected video scenes, olfactory sticks were presented (e.g., with smell of forest). Body scanning was applied with a video in which a Feldenkrais trainer recommended on how to mindfully focus on body parts.

EEG-based analysis associated with relaxation and inhibitory control were recorded before, during and after intervention and eye tracking was applied during intervention and showed significant increases in alpha power and brain connectivity for PwD with AD and controls [3].

Eye movement analysis demonstrated significant differences between PwD (AD) and controls (see Fig. 3): eye blink rate AD > controls, p = .004(**) from the observation of a 3 min video, and significant correlation (Rho = .607, p = .003(**); 3 min video) was achieved between eye movements and the Freiburg Mindfulness Inventory score. The eye blink rate during a smooth pursuit task correlated with the Minimental State Exam (MMSE) with (Rho = -.5768; p = .005**).

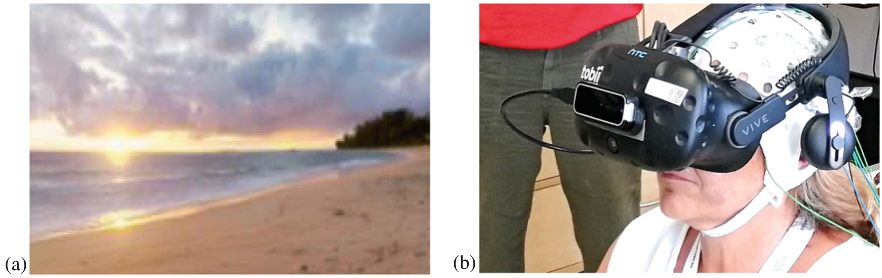


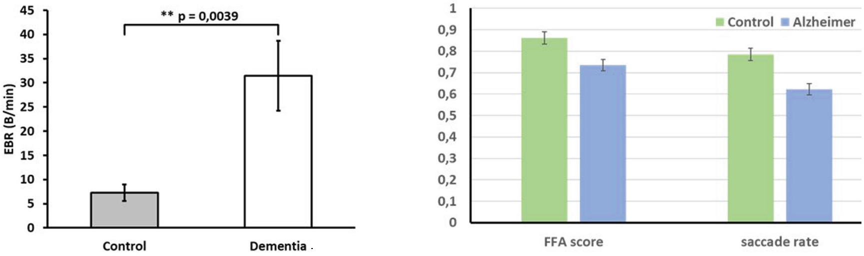
Fig. 2. (a) Beach motif of panoramic video in VR intervention. (b) User of the pilot study with VR headset including eye tracking and EEG sensors.

Fig. 3. Stimuli for the VR-based mindfulness intervention including eye tracking assessment. The stimuli consist of a smooth pursuit-based 3D computer graphics-based (butterfly) and selected video-based (all other) stimuli.

Table 1. Structure and duration of individual stages of the mindfulness intervention.

Training component	Duration	Implementation (VR, real)
Introduction		
• Information concsent	2 min	Without headset
Main activities		
• Body scan Feldenkrais	5 min	With VR headset
• Multisensory experience (visual, audit., olfact.)	15 min	With VR headset
Closing		
• Body Scan Feldenkrais • Breathing exer-cise	7 min	With VR headset
• Good-bye	1 min	Without headset
Total duration	30 min	

These results indicate that even in a very short measurement period of 3 min observation with simple video-based stimuli significant conclusions can be drawn on relevant mental health parameters. Furthermore, results indicate that different sensory triggers enable to make different conclusions on measurement parameters (Table 1 and Fig. 4).



(a) Eye blink rate (b) Mindfulness score (FFA)

Fig. 4. Analysis of eye movement features obtained during the observation of a 3-min video stimulus. (a) On the basis of eye blink rate a discrimination between healthy controls (HC) and AD can be done ($p = .0039^{**}$). (b) The mindfulness score FFA represents an analysis about the mindfulness trait. The results clearly demonstrate significant differences in the FFA between HC and AD. The FFA is in significant Spearman's correlation with the eye movement feature saccade rate ($p = .004^{**}$) and therefore reflects discrimination between HC and AD as well.

5 Conclusions and Future Work

The VR-study demonstrated significant proof that mental health state and mindfulness trait would be measured during intervention. This indicates a huge potential for non-invasive assessment and decision support in the future.

The described VR-based intervention component anticipates numerous opportunities for novel VR-based health care services that enable to measure and assess even during the empowering of the cognitive reserve, to induce sensory activation, raise awareness and motivate for self-regulation, and as a pervasive assessment tool [3].

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Towards Decision Support with Assessment of Neuropsychological Profiles in Alzheimer's Dementia Using Playful Tablet-Based Multimodal Activation

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Abstract. In dementia care there is a lack of knowledge in the context of interventions considering the evolvement of individual cognitive impairments over the course of time. Dementia principally affects distinctive neuroanatomic networks associated with complex cognitive domains, i.e., the neuropsychological profile. The PLAYTIME app - a suite of serious games - was played on a Tablet-PC combining two approaches. One component represented a serious game with integrated eye movement analysis. This functionality is outlined in the MIRA (Mobile Instrumental Review of Attention) framework, a toolbox of attention-based games. The toolbox is used to evaluate executive functions, such as, the inhibitory functionality of controlled eye movements. Another component is represented by the multimodal activation (MMA) app with various cognitively challenging gamified exercises. Both MIRA and MMA showed different profiles of correlation between their play scores and several MoCA (Montreal Cognitive Assessment) sub-scores. The score captured from MIRA as well as from MMA enables to estimate Alzheimer's mental state and establish neuropsychological profiles to identify individual cognitive deficits.

Keywords: Decision support · Alzheimer's dementia · Mental health care

1 Introduction

Dementia represents a category of neurocognitive disorders with the impact of long-term decrease in the ability to think and remember that fundamentally affects a person's daily functioning. Today one of the greatest technological and social challenges is to support adequate and economically feasible care [1].

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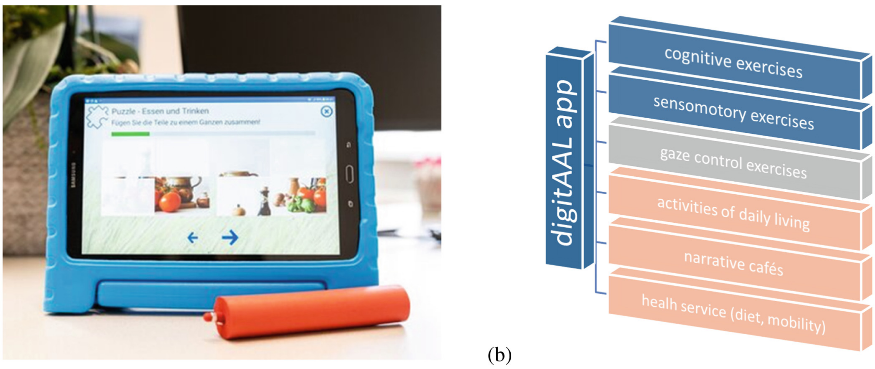
Eventually, there is no cure for dementia [2]. In dementia care there is a lack of knowledge in the context of interventions considering the individual cognitive impairments evolving over time. The disease affects distinctive neuroanatomic networks associated with complex cognitive domains, i.e., the neuropsychological profile. Recently several serious games were successfully evaluated and demonstrated the potential for biomarkers [3]. However, increased accuracy in the estimates of mental state are mandatory as well as the personalization of neuropsychological profiling which is currently research in progress.

The suite of serious games and gamified training combined two approaches in the studies. Persons with dementia (PwD) interacted with integrated versions of two playful training modules, (a) 'MIRA', a serious game with the anti-saccade task, and (b) 'MMA', a suite of cognitive exercises (pairs game, puzzle, text gap filling; see Fig. 1, Fig. 2). Gaming was mostly assisted by trainers while several PwD attained to play alone. A serious game for playful performance on eye movement analysis, in particular referring to the anti-saccade task, was outlined in the MIRA (Mobile Instrumental Review of Attention [15]) framework, a toolbox of attention-based games for the evaluation of executive functions, such as, the inhibitory functionality of eye movements. The anti-saccade test in MIRA is played on a Tablet PC and eye tracking is applied by means of its device-embedded camera. A Tablet-based intervention in terms of playful multimodal training and activation was performed within 10 weeks in Austria, engaging PwD with Alzheimer's disease (AD) living at home. Significant correspondence between the score of gaze-based MIRA and the overall MoCA was proved. MoCA score-based estimates deviated with errors of less than M = 2.6 MoCA points. MMA showed correlation with MoCA and its sub-scores. This enabled to establish the neuropsychological profile - including impairments in visuospatial operations, attention, abstraction, language and recall - by means of game score only.

These successful steps towards daily use of gaze-based games were achieved within the EU project PLAYTIME [16]. This suite of MIRA and MMA training jointly enables



(a) (b)

Fig. 1. Playful Tablet-based Training for Multimodal Activation. (a) Tablet-based Multimodal Activation (MMA) with playful cognitive and physical exercises. (b) MMA app renamed as product, i.e., the digitAAL Life app. It pursues a multicomponent intervention strategy and particularly aims at including serious games with gaze-based assessment (MIRA).

daily estimates of Alzheimer's mental state including individual neuropsychological profiling in order to identify specific impairments' course over time. PwD users accepted the playful training app very well. This pervasive mental assessment tool offers a potential for future long-term monitoring in numerous AD care services.

Fig. 2. Visualization of the diversity of exercise types of the digitAAL Life app, the product version of the PLAYTIME app ([16] MMA, MIRA, etc.), for cognitive activation. There are exercises for training attention ('spot the difference'), visuospatial executive ('puzzle') and sensorimotor training, as well as 'lifestyle' context documentation.

2 Context and Related Work

Although it is known that the course of disease phenotypes in Alzheimer is rather individually specific, longitudinal studies with quantitative evaluation are rare. There is no cure for dementia [2], however, non-pharmacological - cognitive and behavioral - interventions may be appropriate. Programs with physical exercises potentially improve outcomes [3] and are beneficial for the activities of daily living. Cognitive stimulation is decisive for an efficient treatment of dementia. However, insufficient adherence to the training represents a major risk factor for the progress of the disease [4, 5]. It is agreed that multi-component interventions are important, even being accompanied by community settings [6, 8]. Most app-based training programs for PwD focus on cognitive training. Gamified cognitive stimulation for the elderly (Cognifit, Cogmed, Lumosity) and with particular focus on the application for people with dementia, such as, Onto D'mentia, memofit, eMotiva, has been largely exploited. AALJP M3W, CCE, ROSETTA, GAMEUP CAREBOX and ALFA are European research projects that have investigated the monitoring of mental processes and motivated users toperform cognitive and physical activities in several ways. Start-ups, such as, Altoida, Braincheck, Mediaire, Neotiv, and Eyewise provided services for early diagnosis of dementia, however, without activating training.

A comprehensive review on serious games for dementia (SG4D [7]) demonstrated a variety of therapeutic achievements based on physical, cognitive, psychosocial [8] and social-emotional interventions. A taxonomy on SG4D [7] demonstrated that assessment games are still underrepresented in this application domain. A study on play experiences of people with AD [9] emphasized that games should be tailor-made to be suitable for different personalities with AD. SG4D that are personalized for PwD may provide important means to maintain autonomy. Many of current products lack this type of flexibility that most obviously is required. Long lasting motivation is highly relevant to maintain training at homes.

One of the characteristics of Alzheimer's disease (AD) is executive dysfunction [10], such as, lack of inhibition abilities and of the capacity to simultaneously co-ordinate storage and processing of relevant information. In this context [11] found clear evidence for emotion-induced positive enhancement in executive control. The project PLAYTIME aimed at optimal exploitation of the positive impact of emotion and motivation on executive performance, psychosocial contexts and behavior change through the engagement of PwD, to make efficient use of the monitoring of consequences in daily life over long periods of time.

The key objective is to increase quality of life of dementia patients but also of caregivers, in order to stay active at home for a longer time.

3 Apps for Multimodal Cognitive Activation

The objective of the overall PLAYTIME system is to positively motivate PwD to periodic training with digital phenotypes that are generated from interaction and sensing that enable assessment of the neuropsychological profile on a daily basis, to receive recommendations based on digital data with the purpose to deliver more personalized and well-suited exercises for improved training. The motivation is primarily triggered from a suite of playful trainings that adjusts playful training to the individual objectives of the individual user in home care. The overall goal is to involve the person with dementia into a playful multimodal intervention with a 'theratainment' app solution including specific training units for cognitive tasks, physical tasks, as well as to foster playful interaction and in addition make the users aware about the psychosocial context in with a specific component of PLAYTIME [16].

In the presented work, two components of the suite of playful trainings, i.e., MMA and MIRA, are in the focus of experimental investigation. Both modules are relevant for playful training and stimulation of the PwD. It involves the user into training units that relate to different modalities, such as, cognitive and sensorimotor aspects, as described in the following Sections.

3.1 MMA: Playful Cognitive and Sensorimotor Exercises

The MMA component of PLAYTIME is a playful training following the concept of multimodal cognitive activation. It includes a diversity of exercise types for cognitive activation, including cognitive but also sensorimotor exercises. There are exercises for training attention ('spot the difference'), visuospatial executive ('puzzle') and sensorimotor training, as well as 'lifestyle' context documentation (Fig. 2). It is especially suited for people who want to live independently as long as possible.

The digitAAL Life app is the product version of the MMA app for cognitive activation. It is able to present 44 thematic topics, within each of these are 36–47 different exercises per topic, with 16 types of exercises (Table 1), and each with 4 grades of difficulty (level 1 for MMSE < 18; level 4 for MMSE $= 30$), providing in total more than 6000 exercises in 5 languages.

(a) (b)

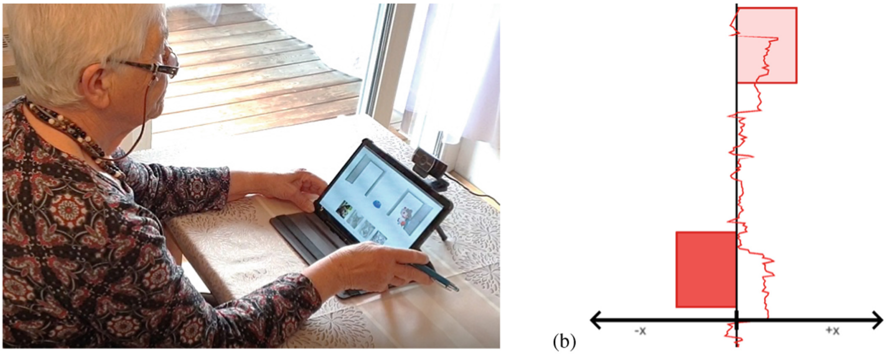


Fig. 3. App MIRA (Mobile Instrumental Review of Attention). A person with Alzheimer's disease plays MIRA, a serious game version of the anti-saccade task. (b) Gaze track over time (top to bottom) with pro- and anti-saccade events.

Table 1. Association of MMA app-based exercise types with expected related MoCA sub-score 1–7 indicated by asterisk ('*'). Statistically significant correlations between exercise and sub-score are indicated by bracketed asterisks ('[*]').

Exercise type	MoCA 1 VisSpEx	MoCA 2 Naming	MoCA 3 Attention	MoCA 4 Language	MoCA 5 Abstract.	MoCA 6 Recall	MoCA 7 Orientat.
KnowledgeText				*	*	*	
Puzzle	*		*			*	*
BoxFinder	*		*			*	[*]
GapFill		*	*	*		*	
Step Sequence	*			*		*	
Math			*		*	*	
Pairs game	*					*	
Outsider played				*	[*]	*	
Knowl. ImageClip	*		*				*
Acoustic Knowledge					*	*	
Difference Puzzle	[*]		*				*
Movement	*					*	
Number Series	*		*		*		

3.2 MIRA: Gaze-Based Serious Game

Progressive neurological diseases like the Alzheimer's disease typically cause specific deficits in eye movement behavior [12]. Crawford et al. [13] have identified by anti-saccade tests that AD patients characteristically suffer from a significant impairment in the inhibition functionality being measured by eye movements. The anti-saccade task requires from the test person a voluntary turning away from an actual stimulus and enables in-depth analysis of the gaze behavior. Recently numerous methodologies of attention analytics were developed with laboratory-based eye tracking technology but there is still a lack in providing opportunity for pervasive and continuous tracking of mental state for people living at home or in nursing homes in order to detect rapid cognitive decline which might occur within months or even weeks.

The MIRA (Mobile Instrumental Review of Attention, see Fig. 3) app [15] stresses the importance of continuous assessment empowered by playful interaction within its gaze interface. It represents a serious game-based version of the anti-saccade task [13] using a device-embedded camera for eye tracking which enables to capture and analyze eye movements during game play. The anti-saccade task detects impulse control problems that indicate executive function-based deficits due to neurodegenerative diseases [13]. The MIRA app enables to perform the evaluation of the anti-saccade test at home, by means of serious games, not in the laboratory or the hospital, and in this sense represents a pervasive measurement paradigm.

4 Assessment of the Neuropsychological Profile

Weintraub et al. (2015 [14]) clarified the contrasting character of early and late stage of AD developments. Their work pointed out that in late stages of AD numerous cognitive functions are impaired such that there is a uniform distribution of deficit over the set of neuropsychological capacities. Consequently, it appears rather difficult to select one single domain that characterizes the syndrome. In contrast, the early stages of AD are more specified in terms of its differentiation among domains that are less impaired and those that are distinctly abnormal. With ongoing progress of dementia, from the early to the late stages, symptom domain boundaries become increasingly blurred and it becomes difficult to discriminate the diseases. From these observations we conclude that the analysis of the cognitive disruptions related to performance in early stage PwD suggests that a one-size-fits-all activation is unlikely to be the most useful approach. Instead, there is merit to a more fine-grained assessment of functional impairments to inform which aspects of cognitive performance could be targeted through training.

In the context of cognitive activation and training, the assessment of the neuropsychological profile is mandatory to understand the individual cognitive deficits in contrast to well working cognitive functions. This specific knowledge is able to tune training more in the direction of loss-making functionalities. In order to become capable to evaluate the full spectrum of cognitive functions it is further necessary to employ a redundant coverage of assessing measurement instruments. In the light of PLAYTIME we investigated the coverage of MoCA sub-scores by exclusively play-based scoring in order to understand how well sensor-based serious games, such as, MIRA jointly with playful training in terms of MMA are able to predict assessment of multi-faceted cognitive functionalities.

5 Experimental Results

MMA and MIRA representing central components of the PLAYTIME suite of serous games were applied on Tablet-PCs. Particularly, PwDs interacted with an integrated version of two serious games: (a) 15 PwD played 'MIRA', the playful version of the anti-saccade task, and (b) 8 PwD played 'MMA', the gamified training suite of cognitive exercises, such as, pairs game, puzzle, text gap filling. Trainers were introducing and assisting the game experience, some PwD were motivated to play alone.

The MIRA-based intervention was applied in Austria for a duration of 10 weeks. The users were PwD with AD living at home. Playful multimodal training and activation was applied to 15 participants ($n = 15$, age $M = 81.7$ years, MoCA score $M = 17.9$). Statistically significant correlation was indicated between the score of gaze-based MIRA play and the MoCA score (Rho = .713**, see Table 2), respectively.

Table 2. Statistically (highly) significant correlation between MIRA app-based game score and various dementia specific neuropsychological test scores (from [15]).

Neuropsychological test	Spearman's rho
Clinical Dementia Rating (CDR)	−.695**
Clock-Drawing Test (CDT)	.607*
Montreal Cognitive Assessment (MoCA)	.713**
MoCA-1 Visuospatial Executive	.729**
MoCA-3 Language	.711**
Bristol Activities of Daily Living Scale (B-ADL): Drink preparation	−.608*
Bristol Activities of Daily Living Scale (B-ADL): Transferring	−.586*

Individual MoCA score estimates were generated from a polynomial estimation model with errors of less than $M = 2.6$ MoCA points. The MMA app-based game scores showed statistically significant correlation with the MoCA score (Rho = p = .755*, see Table 3) and further MoCA sub-scores.

In summary, the neuropsychological profile could be established from the game scores of MIRA and MMA apps including estimates about impairments in visuospatial operations, attention, abstraction, language and recall.

Table 3. Statistically significant correlation between the game score that was achieved from playing the specific MMA app-based exercise type with the MoCA sub-score has been found for "Visuospatial Executive", "Abstraction" and "Orientation".

Statistics	MoCA 1 VisSpEx	MoCA 3 Attention	MoCA 4 Language	MoCA 5 Abstraction	MoCA 6 Recall	MoCA 7 Orientation
	"Difference puzzle"	"Puzzle"	"Knowledge text"	"Outsider played"	"Pairs game"	"Boxfinder"
Spearman's rho	0.836	0.718	0.376	0.784	0.621	0.781
p-value	**0.016***	0.071	0.381	**0.036***	0.110	**0.030***

6 Conclusions and Future Work

This research provides first evidence about the usefulness of combining different modules in a systematic manner in order to achieve estimates about functional categories of cognitive deficits being represented by the different categories of the MoCA sub-score. This work indicates first successfully validated stages towards the daily use of gamified cognitive and sensorimotor activation and training as well as towards gaze-based serious games for rehabilitation. The PLAYTIME components MIRA together with MMA enable continuous estimates of the mental state of Alzheimer's disease over the course of time based on high adherence values. The specific contribution of this work is to map game scores to estimated capacities and deficits of individual neuropsychological profiles. Applying this method within long-term studies will enable to continuously assess individual cognitive impairments and focus then rehabilitation efforts on the most promising cognitive functionalities.

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THERADIA: Digital Therapies Augmented by Artificial Intelligence

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Abstract. Digital plays a key role in the transformation of medicine. Beyond the simple computerisation of healthcare systems, many non-drug treatments are now possible thanks to digital technology. Thus, interactive stimulation exercises can be offered to people suffering from cognitive disorders, such as developmental disorders, neurodegenerative diseases, stroke or traumas. The efficiency of these new treatments, which are still primarily offered face-to-face by therapists, can be greatly improved if patients can pursue them at home. However, patients are left to their own devices which can be problematic. We introduce THERADIA, a 5-year project that aims to develop an empathic virtual agent that accompanies patients while receiving digital therapies at home, and that provides feedback to therapists and caregivers. We detail the architecture of our agent as well as the framework of our Wizard-of-Oz protocol, designed to collect a large corpus of interactions between people and our virtual assistant in order to train our models and improve our dialogues.

Keywords: Healthcare · Cognitive disorders · Digital therapies · Artificial intelligence

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1 Introduction

Today's medicine is increasingly based on a Preventive, Personalised, Participatory and Predictive approach (a.k.a. 4Ps medicine), where digital plays a key role in this transformation. Beyond the simple computerisation of healthcare systems, many non-drug treatments such as digital therapies are now possible thanks to the progress made in both digital technology and artificial intelligence (AI). One such example is cognitive remediation, which is a digital therapy based on interactive and configurable stimulation exercises offered to people suffering from cognitive disorders [1, 2]. The efficiency of these new treatments, which are still mainly offered face-to-face by therapists, can be greatly improved if patients are able to pursue them at home, as it increases clinical efficiency without the need to make visits to the hospital [3, 4]. However, conducting some sessions in autonomy where patients are left to their own devices can make adherence to treatment difficult, which is a major issue [5].

One possible way to increase adherence to treatment is to accompany patients throughout the course of therapy. As cognitive remediation exercises are presented to patients through an application running on digital devices, it is possible to design and integrate a virtual agent that acts as an empathic assistant supporting progress throughout the digital therapy.

This is the purpose of THERADIA, a 5-year project structured in three main phases: (i) initialisation—architecture design, first implementations of components, (ii) collection of real data, and optimisation—training of AI models, improvements of technical components, and enrichment of dialogues, and (iii) clinical study—validation of the efficiency of the assisted digital therapy on patients with medical conditions. After one year of work, the initialisation phase led to the design of a Wizard-of-Oz experiment.

In the remainder of this article, we present related work on virtual agents as personal healthcare assistants, then introduce the THERADIA project and our virtual agent, as well as the Wizard-of-Oz framework designed to collect pertinent interaction data, before giving concluding remarks.

2 Related Work: Virtual Agents as Personal Healthcare Assistants

There is a plethora of virtual agents that act as personal healthcare assistants on digital devices, even for virtual worlds' residents [6]. A recent systematic literature survey on the use of conversational agents or chabots in the field of psychiatry for the screening, diagnosis, and treatment of mental illness has shown the benefits of virtual assistants in psychoeducation and self-adherence, with a high level of satisfaction reported from the users, suggesting that they would be an effective and enjoyable tool in psychiatric treatment [7].

Virtual assistants have been able to perform speech recognition and synthesis—for producing and understanding multimodal forms of expression—since at least two decades [8]. Recent advances in artificial intelligence have made it possible to identify information related to health and affect [9, 10], and to generate emotional expressions and attitudes [11, 12]. In order for a virtual assistant to be truly effective in supporting patients throughout the therapy, it must be able to adapt to the different interlocutors and their expressiveness, and therefore be able to detect and synthesise different conversation styles.

3 THERADIA: An Empathic Virtual Assistant to Accompany Digital Therapies

The THERADIA project reunites a consortium of academic and industrial researchers who aims to develop a virtual therapeutic assistant that constitutes the relay and the interface between the patient and the therapist, but also with the caregivers. Following the path of affective computing, we believe that such virtual assistants should be able to not only monitor the emotions and general well-being of patients throughout the digital therapy, but also respond to them in an appropriate manner [13]. In addition, we believe that feedback about the progress or issues faced by the patient during the digital therapy is needed, with specific information given either to caregivers or therapists. We have designed the architecture of such an empathic virtual agent, which encompasses several modules that are sketched in Fig. 1 and detailed below. The system acts as a visioconference, with specific data-driven modules to analyse the expressions of the patient and generate appropriate responses from the virtual agent.

The first level of modules extracts information from the patient's audiovisual stream then the dialogue management selects an appropriate interaction among multiple scenarios which is finally played by the 3D female avatar and streamed to the patient browser as an audiovisual stream. A standard session is basically structured in five main phases:

- welcoming dialogue: during the first session this dialogue helps the assistant to collect information about the patient. In the next sessions, the dialogue takes care of the patient's motivation and mood before starting the training.
- exercise introduction: depending on whether this is the first time the patient is introduced to a new exercise or not, this dialogue introduces the gameplay and the goal of the task or recalls feedback from previous performance.
- during exercise: the assistant is not visible and remains passive and lets the patient run the task. It only monitors the patient's attention or detects special events that would require stopping the task.
- result analysis: at the end of each exercise the assistant positively comments on the performance of the patient and rewards the training. Then, a new exercise is launched until the training session is over, which usually lasts 30 to 45 min.
- debriefing dialogue: at the end of the session, the assistant rewards the patient for completing the session and gives an appointment for the next session.

Audio, Visual, and Textual Descriptors

Continuous audiovisual descriptors are extracted from state-of-the-art representations such as Mel-Frequency Cepstral Coefficients (MFCCs) for audio, and Facial Action Units (FAUs) for video, but also from self-supervised representations [14, 15]. Once the speech stream is segmented by the content process layer, a speech recognition module performs its transcription, which is then processed to extract linguistic descriptors.

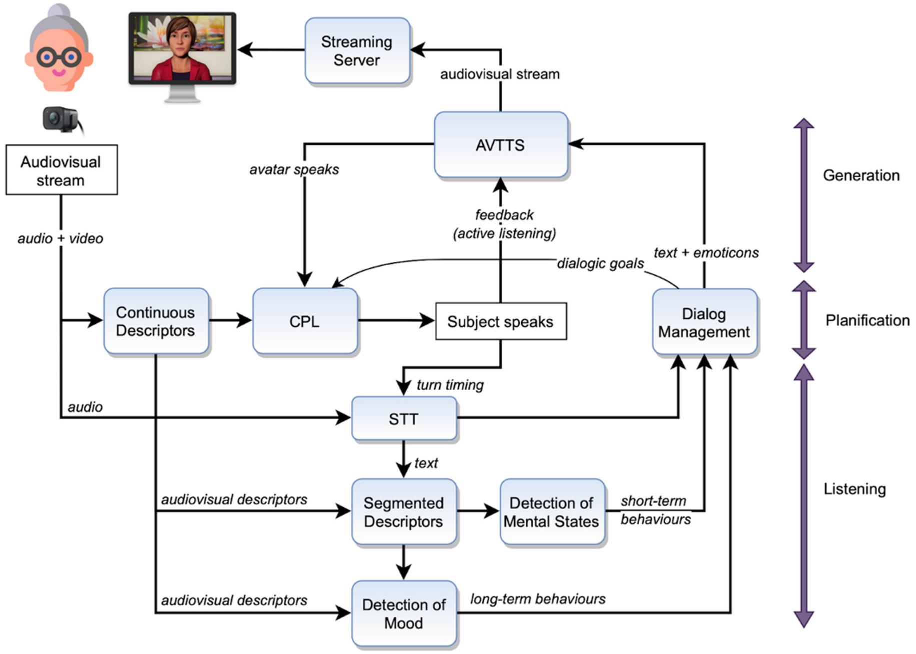

Fig. 1. Flowchart of the THERADIA system designed for accompanying patients suffering from cognitive disorders when completing digital therapies; CPL: content process layers, STT: speech-to-text, AVTTS: audiovisual text-to-speech synthesis.

Content Process Layer

The aim of the content process layer is to incrementally detect turn taking opportunities [16]—using both linguistic and prosodic features [17]—so that the agent can lead the conversation and stick to the dialogic objectives, especially when it has to give back the floor after initiating an open-ended question. This component is coordinated with the "active listening" component responsible for providing incentives and feedback at key instants of the interlocutor's speaking time.

Dialog Management

The Dialog Management is composed of a Natural Language Understanding (NLU) module that interprets the patient's speech and emotions and passes them to the dialogue engine, which runs encoded dialogues through the viky.ai platform. Interaction scenarios are defined by a group of speech therapists (used to run cognitive remediation sessions) using a dialogue editor.

Detection of Emotions, Mood, and others Mental States

Emotional AI is mainly driven by either categorical labels of emotion [18], or dimensional representations of core affect [19]. Appraisal theories suggest that these approaches are however too reductive to conceptualise the complexity of the range of human emotions. According to the Component Process Model (CPM) [20], emotions can be distinguished by sequences of cognitive appraisals, where apparent motor expressions produced by individuals (facial expressions, voice prosody) contain key markers of appraisal sequences [21]. Our emotion recognition system is based on Recurrent Neural Networks that model contextual dependencies between signals and labels as defined in the CPM.

Expressive AudioVisual Text-To-Speech Synthesis
Typical text-to-speech synthesisers are based on end-to-end approaches where the synthetic speech signal is produced in two steps: a sequence-to-sequence model (SSM) warps a sequence of characters to a sequence of mel-spectrogram frames—e.g., the Tacotron2 encoder-attention-decoder framework [22]—that a neural vocoder further maps to an acoustic signal. Our system is based on a state-of-the-art TTS trained on 100 h of audiobooks that is being extended to include: (i) a joint prediction of spectrograms and animation parameters using multi-head attention, (ii) expressive embeddings [23], and (iii) behavioral alignment by biasing part of the expressive embeddings with features of the conversational partner [24].

Automatic Feedback Generation
Based on examples provided by domain experts, we aim to automatically generate reports summarising the cognitive remediation carried out at home by patients. This task can be decomposed in the following steps: (i) identify, aggregate, select and structure the relevant information to communicate, (ii) transform this structured information into a coherent multimedia document, and (iii) adapt the production to the generation criteria such as type of recipients (therapist or caregiver), period to be summarised, and length of the summary.

4 Experimental Data Collection Using a Wizard-of-Oz

The collection of data in situ from the population of interest is essential for the development of the THERADIA virtual assistant: it provides ground truth behaviors of the patients interacting with a faked embodied conversational agent and optimal control policy of the agent by the cognitive gift of the human pilot. Such data are essential for feeding the multiple trainable components of the autonomous system (emotion detection, SST, TTS, etc.). We are particularly interested in coadaptation mechanisms, both short-term (using sets of pre-defined interaction profiles) and long-term (using continuous training).

The virtual assistant is driven in real-time by a human pilot, who is filmed by a high-quality camera, cf. Fig. 2. Head movements, gaze, speech, and articulation are captured to drive the 3D avatar whose rendering is casted to the patient screen. As introduced earlier, the virtual assistant does not interfere with the exercising: it intervenes before, between and after the exercises to provide the patient with instructions, rewards and feedback. The human pilot's interventions are scripted by the dialogue system, so that the recorded conversations stick to what the automatic system is capable of, thanks to a teleprompter: Dialogue acts and expected responses of the subject are overlaid onto the pilot's screen where the subject face is displayed. Alternatively, the pilot's screen displays the patient's screen when he/she is exercising, in order to ground further interventions. The system logs timestamped dialogue states and continuously monitors behaviors of conversational partners: we use Dynamixyz® technology to monitor the facial movements of the human pilot and the patient. A gaze correction is automatically applied to the pilot's eye movements for enabling eye contact between the avatar and the patient. Each exercising session delivers three videos coming from the human pilot's camera, patient's camera and patients' screen, plus tracking audiovisual features of both partners, and timestamped logs of exercising along with conversation switches and dialogues.

Fig. 2. A human pilot (left) interacts with a patient (right) through a virtual assistant (on screen in the right image) that is automatically animated based on the facial expressions of the pilot (See https://www.theradia.fr/AHFE2021 for more pictures and videos.).

5 Conclusion

We have introduced the THERADIA project, whose aim is to endow a system for autonomous cognitive remediation with a conversational agent capable of providing social presence, coaching and support when necessary. Challenges facing the implementation and long-term acceptability issues of such a technology are numerous. The Wizard-of-Oz system fulfills a twofold purpose; iteratively assess scripted dialogues and provide trainable components (turn management, dialogue, active listening, TTS, STT, etc.) with ground truth behaviors. "What to do" (saying is the main but not exclusive action the system can perform) and "How to do it" are dual problems for the agent. The human pilot continuously identifies failures of the dialogue management and her improvisation phases are constantly considered in order to improve the ability of the virtual assistant to appropriately act and interact with the patient. The final system has been designed as a visioconference: we will soon be able to monitor in-the-wild interactions, with home environments and on-demand exercising. It also has to be extended to handle all stakeholders (therapists and caregivers) and take into account all experiences into its episodic memory. A final challenge is to explore the impact of this assisted autonomous exercising on the health ecosystem.

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Cognitive Assessment and Physical Strain of First Responders and Action Forces

Electrotactile Stimulation, A New Feedback Channel for First Responders

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Abstract. This paper presents the early results of research aiming to develop a novel system for unobtrusive and intuitive electrotactile feedback for first responders. The system leverages the multi-pad stimulation technology based on spatiotemporal modulation of the stimuli. Two-point discrimination threshold mapping was performed in potential electrode placement locations, defined from the usability perspective by the first responders in initial co-development sessions. Based on these results a custom electrode design was proposed and validated in six healthy volunteers. Psychometric testing was conducted to determine spatial discrimination between stimuli produced by the multi-pad electrode. The average success rate of 80% indicates that the proposed approach is feasible.

Keywords: Electrotactile stimulation · Mission-critical communications · H2020 · Biofeedback · First responders

1 Introduction

For the first responders operating in extreme conditions, like wild-fires or blizzards, situational awareness is crucial for both effectiveness and safety. However, when the environmental conditions impair their senses, the first responders are forced to rely on the technology-enabled external feedback [1]. Tools relying on technologies for auditory and visual communication are well established for alerting users of eminent dangers, like declining physiological state or environmental threats, and they leverage flashing lights and/or alarming sounds [3]. However, in overwhelming environments where sight or hearing are focused on different targets, saturated or degraded, tactile feedback can be used to bring additional information to the first responders [4].

This paper presents the early results of the SIXTHSENSE project, a research and innovation action aiming to develop new methods for unobtrusive and intuitive feedback that relies on electrotactile, rather than auditory or visual communication [2]. The

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concept leverages otherwise unused bandwidth of the sense of touch, which has the potential to significantly contribute to situational awareness [5]. It applies the principles of electrotactile displays, where low-intensity electrical current is delivered to the skin to activate nerve fibres and elicit tactile sensations [6]. This communication channel can be used to convey messages intuitively and allow users to quickly interpret and react to the situation by leveraging spatiotemporally modulated stimuli [7].

The feasibility of this approach, based on our multi-pad stimulation technology, was successfully demonstrated in myoelectric hand prosthesis use case [8–10]. It was shown that spatiotemporal modulation of electrotactile stimulation allows subjects to reliably (>90%) discriminate between a large number of messages after a few training sessions [7]. However, reliability requirements for first responder feedback technology are stricter. Misinterpreted feedback by a first responder can have dire consequences, and a tactile message needs to be cognitively registered and interpreted despite potential distractions in the environment. Also, the use in conditions of increased physical activity and with personal protection equipment need to be considered.

Early end-user feedback revealed external limitations in the system placement, indicating the trunk as the most viable option. This is a large area with many options for electrode placement and topology. Since the perception of stimuli is shown to depend on the body site [11, 12], proper selection can help address the challenges specific to the selected use case. A parameter of particular interest is the spatial resolution, which varies greatly in different areas of the torso, but is lower than on the arms and hands [13]. There are well-established protocols for determining spatial resolution, specifically the two-point discrimination threshold (TPDT) test [14, 15] and the spatial discrimination (SD) test [13].

In the following sections, we present the process of designing and testing a novel system for electrotactile feedback. First, exploratory investigation of the psychometric characteristics of the candidate electrode positions was conducted to select the placement strategy and the topology design. Based on these findings, a new electrode design was developed, prototyped and validated.

2 Methods

The study was performed in two stages. First, the exploratory psychometric tests were performed with the aim to determine the two-point discrimination properties of the candidate positions selected according to the early end-user feedback. Based on the results of the exploratory stage, the electrode prototype was manufactured and then tested in the second stage of the study.

2.1 Subjects

The presented study was conducted in 6 healthy volunteers, 3 females and 3 males, aged between 23 and 34. All procedures and potential risks were explained to the subjects, who signed the informed consent form.

2.2 The First Stage

Setup

The charge-balanced biphasic pulses were delivered via a custom-made electrode array with 16 circular pads used as cathodes and a common anode (ValuTrode, Axelgaard, US). Each cathode pad had 4.75 mm radius, and there was 12 mm centre-to-centre distance between the pads. The stimulation signals were generated by the current-controlled MAXSENS stimulator device (Tecnalia Research & Innovation, ES), wirelessly controlled using an Android application, custom made for simple and quick execution of the testing protocol. The complete setup is shown in Fig. 1.

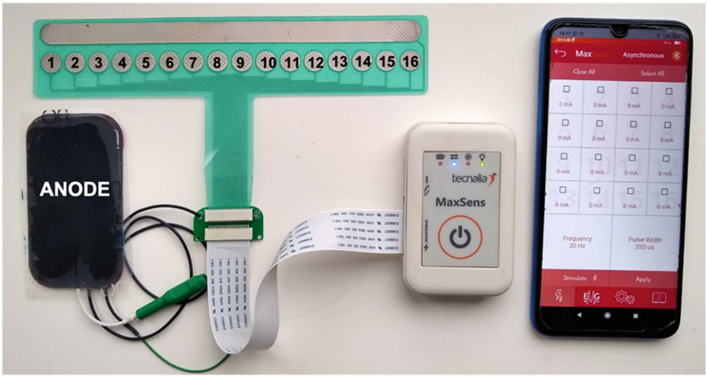

Fig. 1. The experimental setup, comprising the electrode array, the separate anode and the stimulator unit connected to an Android app for simple protocol implementation.

Protocol

The subjects were comfortably seated, with their back turned towards the examiner. The anode was positioned on the top of the left shoulder blade and the electrode array was placed in four candidate positions considered in this stage: H – the array was horizontally oriented, centrally aligned with the anode and 3 cm below; V_M – the array was vertically oriented and placed medially about 3 cm from the spine; V_L – the array was vertically oriented and placed laterally about 12 cm from the spine; and V_{EL} – the array was vertically oriented and placed extremely laterally on the coronal plane intersection line. All electrode positions explored within this stage are shown in Fig. 2. The electrodes were fixed with medical adhesive tape to secure the contact with the skin.

The experiment started with the calibration where the current amplitudes at which the stimulus was first sensed and then at which the sensation was clear and localised were determined for each pad in the array. Starting from pad no. 1, the subject gradually increased the stimulation amplitude with a 0.1 mA step and noted the appropriate thresholds by clicking on the "sensation/localization threshold" button in the app. The application allowed the subject to return to previous pads and recalibrate, if necessary. The remaining stimulation parameters, frequency and pulse width, were constant during the experiment and set to 30 Hz and 400 μs, respectively.

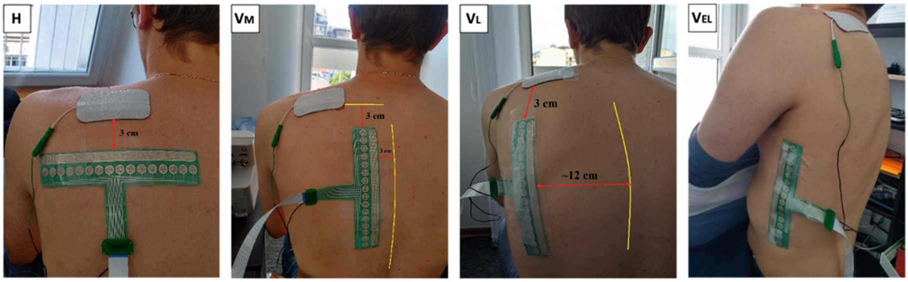

Fig. 2. Four tested positions of the electrode array: one with horizontal orientation – H and three with vertical orientations – V_M, V_L and V_{EL}. The position of the anode was fixed.

Once calibration was completed, the TPDT test was conducted. Here, current amplitudes were set to the localization threshold values obtained for each pad, while other stimulation parameters were kept the same as in the calibration.

The TPDT test was performed following one of the accepted methods where the stimuli gradually approached one another [16]. In the setup used here, pad no. 1 was always active and it was combined with other pads to form a pair. The first stimuli were generated using two pads with the maximal distance (pads no. 1 and 16), and then, the distance was decreased in each step, until pads no. 1 and 2 were activated in the last step, amounting to a total of 15 steps per trial. The subject was presented with an app interface with two buttons, labeled with "1" and "2", and was instructed to select the option corresponding to the number of perceived stimuli locations. The two-point discrimination threshold was defined as the distance between pad combination that was the last reported as two separate stimuli. The calibration and the TPDT test lasted between 10 and 15 min per electrode position, allowing the whole protocol to be performed in under an hour.

2.3 The Second Stage

Based on the results obtained in the first stage, the SIXTHSENSE ALPHA electrode was designed and validated to determine the spatial discrimination properties. The design was selected to maximise the differentiation of delivered stimuli by leveraging the effects observed in the first stage. As shown in Fig. 3 the electrode comprises two large pads on both ends and a 3 × 2 matrix in the middle. Such design would allow the implementation of complex messages, e.g. where the variable type is indicated by the large pads, while the value is coded through the matrix.

Setup

The setup was based on the alpha prototype of the SIXTHSENSE system for electrotactile feedback. The novel electrode comprised 8 cathodes: 6 circle-shaped and 2 rectangles with rounded corners, and a single anode distributed around each pad in a quasi-concentric architecture. Each circular pad had 8.5 mm radius with 45 mm centre-to-centre distance between the pads, and with 3 mm edge-to-edge distance to the anode. The rectangular pads' dimensions were 45 mm × 30 mm, and their distance was 200 mm.

The edge-to-edge anode to cathode distance for smaller and larger cathode-anode pairs was 3 mm and 8 mm, respectively.

As in the previous stage, charge-balanced biphasic pulses were used. To allow safe and effective electrotactile stimulation with the proposed electrode design we relied on the Bi-Matrix stimulation system prototype (Global Electronic Solutions, RS). Stimulation control was performed through a LabView (National Instruments, USA) application running on a connected Windows tablet. The complete setup is shown in Fig. 3.

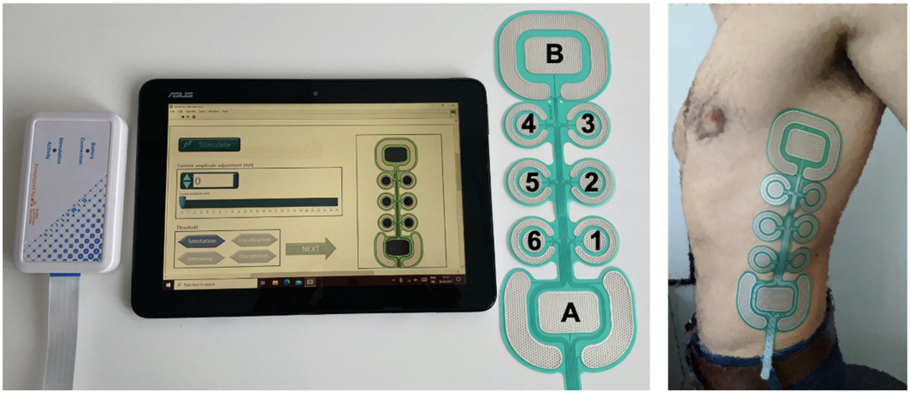

Fig. 3. Left: experimental setup comprising the stimulator unit alpha prototype, the LabView application for simple protocol implementation and the SIXTHSENSE ALPHA electrode with annotated pads. Right: The electrode placed on the subject.

Protocol

The subjects were standing and presented with the tablet PC with a dedicated LabView app. The electrode was placed at V_{EL} position, as shown in the right panel of Fig. 3, and then secured with a stretchable girdle. The calibration process was performed in the same manner as in the previous stage. The following spatial discrimination (SD) test included three phases: familiarization, reinforced learning, and validation.

During the familiarization phase, the pads were activated sequentially, starting from pad B, through six pads of the 3×2 matrix and ending with pad A (as labeled in Fig. 3). The stimulation lasted two seconds per pad, while the active pad was marked on the electrode drawing presented on the screen. The sequence was repeated three times.

In the following phase of reinforced learning, the pads were activated randomly (2 s long stimuli), and the subjects were asked to guess the active pad by pressing the corresponding pad on the electrode representation in the app. The app provided visual feedback regarding the correct answer lasting 1 s. If the answer was correct, the pad was marked green. If not, the correct pad was indicated with red colour. The pause between two stimuli was at least 1 s. The pads were activated in five pseudo-randomized sequences, with each pad activated only once in a sequence of eight stimuli.

The final phase of the experiment, the validation, followed a protocol similar to the reinforced learning. The subjects identified the active pad on the electrode drawing presented in the app but the correct answers were not shown. Again, there were five sequences where each of the eight pads was activated in a pseudo-random order. The outcome measure was success rate (SR) in correctly identifying the active pads.

3 Results

The TPDT, assessed in the first stage of the experiment as the distance between two pads that could be perceived as two separate stimuli, is presented in the left panel of Fig. 4 for four different positions of the electrode array. Median (interquartile range) values of TPDT were 72 (12) mm, 42 (36) mm, 54 (24) mm and 42 (12) mm for positions H, V_M, V_L and V_{EL}, respectively. With the lowest TPDT in terms of both median and interquartile range, the extreme lateral position (V_{EL}) was selected for placing the custom-designed electrode in the second stage of the experiment.

The right panel of Fig. 4 shows a confusion matrix characterizing the spatial discrimination of eight pads of the SIXTHSENS ALPHA electrode averaged across six subjects. As expected, the highest mean SRs were obtained for pads A and B (93.3% and 96.7%). The subjects could identify six matrix pads with an average SR of 75.0% ± 16%, ranging from 53.3% for pad 1 to 93.3% for pad 3. SR for individual subjects ranged from 60.0% to 92.5%, with an average of 80.0% ± 11.1%.

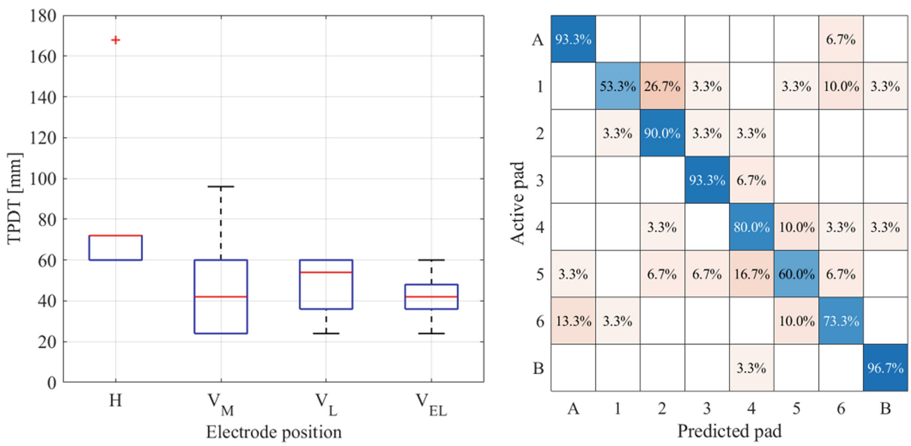

Fig. 4. Left: Boxplots of TPDT (in mm) assessed during the first stage of the experiment for four proposed electrode positions in six healthy volunteers. Right: Confusion matrix of recognition of eight electrode pads (annotated as in Fig. 3) averaged over six subjects.

4 Discussion

The results of the experiments in the first stage showed that the horizontal position (H) had the largest median TPDT and for one subject the sensation was unintelligible. Conversely, this placement showed the largest repeatability for the other five subjects, indicating that spatial discrimination in the horizontal direction may be reliable, provided that the stimuli are sufficiently spaced. All vertical configurations had lower median TPDT, but with higher variability. These results are in line with the previous studies performed on the back of the neck that reported a mean TPDT of 37 mm [12] and 45.9 mm [15]. Of the three options, the extreme lateral position (V_{EL}) was selected as the best candidate due to the lowest median and largest consistency across the subjects. These findings suggest that vertical orientation could be the best option for the novel electrode design, but a matrix configuration could be beneficial if the horizontal separation is sufficiently large.

Based on this, a hybrid electrode topology shown in Fig. 3 was proposed. The electrode was envisioned as a medium to concurrently convey two types of messages. The large pads A and B would be used for single state messages, such as predefined alarms, while the 3×2 matrix would leverage spatiotemporal modulation to convey multilevel information, such as heart rate levels. The proposed concentric anode/cathode configuration is traditionally used in other applications of tactile feedback (e.g., restoration of feedback in prosthetics), as it is believed to facilitate the stimuli recognition due to a localized current flow [6]. However, our previous research showed no significant difference in spatial discrimination when comparing concentric versus adjacent cathode/anode configuration [7]. The determining factor was safety consideration, as the concentric design reduces the possibility of generating potentially harmful levels of current density in case a cathode or an anode peels off, resulting in only partial contact with the skin.

The results of spatial discrimination tests performed with this electrode justify the design choice. Overall results for this electrode design are comparable to our previous findings [7], where spatial discrimination for 8-point stimulation around the forearm had a similar success rate of $74\% \pm 15\%$. The confusion matrix shown in Fig. 4 reveals that pads A and B were recognised with a high reliability and were seldom confused with a neighbouring pad. Discrimination of the stimuli of matrix pads was overall less successful, with exception of pads 2 and 3, which were also recognised with $>90\%$ success rate. Three pads with the lowest success rate (1, 5 and 6) were mostly confused with their vertical neighbours. This is in line with the results of the first stage, as half of the subjects would have the V_{EL} TPDT larger than the centre-to-centre distance of matrix pads. Nevertheless, it is interesting to note that confusion was lower between the horizontal neighbours, even though the TPDT measured in H position was higher. This might be explained by the electrode placement, where horizontally neighbouring pads were on the different sides of the coronal plane intersection line, and the frontal/dorsal relation might have facilitated the distinction. This effect could be effectively exploited to increase system reliability, but confirmation through additional investigation is required.

It should be noted that identical stimulation pattern was used on each pad in the spatial discrimination test. The full potential of this technology is only revealed when dynamic stimulation patterns are employed to communicate complex multivariable information. Based on the past experience [7–10] it is expected that by leveraging this modality the reliability of feedback will drastically increase. It is in this regime where the matrix topology can be an effective tool for concurrent communication of multiple messages. Implementation of multivariable coding through spatiotemporal modulation of stimuli and subsequent validation in field tests with first responders is the following step of the presented research.

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Multisensory Wearable Vital Monitoring System for Military Training, Exercise and Deployment

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Abstract. Military organizations have extensive technological solutions to precisely monitor machines and operating equipment. In recent decades, extensive research and development projects have been launched focusing on the physiological monitoring of soldiers, with new opportunities arising from innovative developments in the field of biosensors. This paper describes the main objectives of the VitalMonitor project, which is carried out in the frame of the Austrian Defence Research Program FORTE (FORTE - Austrian Defence Research Program; https://projekte.ffg.at/projekt/3781447). The project focuses on the development of a real-time monitoring system for situation-dependent physiological load on soldiers based on innovative body worn biosensors integrated into clothing or equipment. Intelligent sensor fusion and data analysis methods enable an overview of the actual physical stress situation in military training, exercises or missions. The analysis of scenario-based physiological requirements will be the basis for the optimization of physical resilience as well as operational readiness and will eventually reduce the risk for dangerous situations caused by physical exhaustion.

Keywords: Military training · Physiological strain · Wearable biosensors · Real-time physiological stress monitoring · Smart textiles

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1 Introduction

In addition to the determination of psychological and cognitive requirements, extensive research capacities have been invested in the analysis of physical performance requirements for the successful accomplishment of military tasks and activities in recent years. The reasons for this research are findings from current deployment scenarios of large armies and real-world problem areas that make it increasingly clear that the physical performance of soldiers can have a decisive influence on operational readiness and finally can influence the outcome of the military success. It should also be noted that analyses of current military scenarios indicate an overall increase rather than a decrease in the physical stresses that occur. Although advances in defence technology are reducing the weight of individual items of equipment and weapons and are also improving their ergonomics in some cases, it can also be recognized that the number and total amount of military equipment to be carried and operated by individual soldiers is gradually increasing [1].

Depending on specific military activities, there are completely different requirements and psychophysiological stress patterns. As a result of the high level of technology in military work tasks, psychophysiological performance is of central importance for successful mission accomplishment. Relevant studies from the military sector are often difficult to access or not available. However, published studies from the civilian research sector and findings derived from them cannot be fully transferred or can only be transferred in part. For example, the combination of heat and physical work is one of the greatest stressors on the human organism, which can lead to severe performance losses and critical health situations within a short period of time. Physical activities, in military clothing, especially high level protective clothing ensembles, like Bomb-Suits or CBRN-Suits often lead to high-intensity physiological stress and require the collection and assessment of physiological measurements and analyses for targeted risk and stress management.

Due to the military-specific working conditions and multifactorial stress situations, the transferability of ergonomic principles and experience from the civilian research sector is only possible to a limited extent [2]. Accordingly, own research methods must be implemented, with which the workloads in the military can be recorded and evaluated according to scientific criteria, taking into account weapon- and function-specific characteristics [3]. Recent advances in the field of wearable bio-sensors including higher performance, better measurement accuracy and battery life by simultaneously reducing size and cost allow for new applications of real-time wireless body-worn sensor systems. A real-time system for physiological status monitoring (RT-PSM) offers new opportunities for military purpose with individual assessment of soldiers' performance limits. However, most commercially available systems do not meet the relevant military requirements. They are usually lacking validated methods and algorithms to derive essential information in real time, and are not designed to be integrated with the soldier technological ecology [4].

The main objective of the VitalMonitor project is therefore to conduct exact stress analyses in realistic scenarios ("field tests") using mobile spirometry solutions and wearable sensors, and to develop a real-time monitoring system for soldiers based on decision support system including scenario-oriented stress models and innovative analyses methods. Extensive tests in laboratories and real-life environments with different sensor systems are to ensure that the developed solutions will also achieve a high level of usability among soldiers.

2 Motivation and Requirements

Challenging military work tasks often require a high level of responsibility, and in case of a decline in mental performance this can have critical consequences. Reduced concentration and reaction cause delayed or possibly even wrong decisions, which can have fatal consequences [2]. Statistical evaluations from the U. S. Army Combat Readiness Center [5] show that approximately 80–85% of all military accidents are directly related to cognitive performance degradation. Precise knowledge of the stress situation in relation to real deployment scenarios as well as the individual burden in such situations enables monitoring of the individual stress and individual stress control in order to avoid critical individual capability changes (e.g. action and decision errors) through appropriate measures. High physical performance also increases cognitive performance in stressful situations. A real-time monitoring system, which is able to measure changes in physiological parameters such as heart rate, heart rate variability, skin conductance, core body temperature, etc. and to analyse the measured values intelligently, enables both mission commanders and soldiers to control their individual stress situation in a targeted manner and thus avoiding poor performance. In many operational scenarios, soldiers and special forces are expected to have a high level of training paired with peak physical and mental performance. Activities carried out in special military functional clothing, such as CBRN (Chemical-Biological-Radiological-Nuclear) or EOD (Explosive Ordnance Disposal) suits, inhibit highly intensive physical loads. Those activities require collecting practically relevant load parameters on the basis of physical performance and analyses for targeted risk and load management.

In this project, the focus is put on two specific task forces, i.e. CBRN defence and explosive ordnance disposal personnel. The following essential requirements for a real-time monitoring system have been derived:

- Real-Time Assessment of Physiological Status
- Decision Support for Military Commanders
- Determination of Optimized Work-Rest-Cycles
- Prevention of Physical Overstraining in Training & Missions
- Personalization of Physical Fitness Training

A critical stress parameter for military special forces performing their activities in an CBRN or bomb suit is the core body temperature and its associated heat stress as well as critical developments in water or electrolyte balances. Depending on the environmental situation (humidity, climate, etc.) and individual work stress, sweat losses of 1l/h can occur over longer periods. Physical performance and the individual heat tolerance depending on several factors are important parameters in this context [6].

On the basis of the data obtained and the information derived, it is possible to optimize the individual resilience and referring to this training processes. Personalized training concepts with the integration of adaptive training methods enable improvements of the individual performance level. Considered over a longer period of time, the data from this monitoring system also allow an analysis of the health status of the individual soldier as well as his fitness status, which brings an important individual added value.

3 Objectives and Workflow

For the development of soldier targeted real-time solutions, applying the monitoring of situation-dependent psychophysiological stress indicators, the use of different body-worn or in clothing/equipment integrated biosensors is recommended. The following innovative objectives are defined within the framework of the project implementation:

- Evaluation of new sensor types for stress measurement in military scenarios and their use in military training, exercise and deployment
- Integration of innovative sensors (including prototypes) into the VitalMonitor "Smart Clothes" solutions for laboratory and simulated field measurements
- Development of a concept for an individualised performance baseline for CBRN and EOD personnel employment standards
- Derivation of the body core temperature based on the measurement of the skin temperature
- Development of analysis models to conduct performance diagnostics based on powerful low-cost sensor technology (machine-/deep learning approaches)
- Derivation of time-optimized (simplified) analysis models to allow valid, near-real-time analysis of sensor data for time-critical real deployment scenarios
- Innovative data management at different levels of abstraction, which enables end-to-end transparency from raw sensor data to analysis results to interpretations and evaluations
- Expert management tool that provides experts with a transparent view of the entire analysis process - from raw data to the models used and evaluation results

In order to enable a successful realization of the targeted innovation concepts and technical developments, a consistent project workflow was developed and the necessary working steps were defined in detail (see Fig. 1).

In order to be able to induce and evaluate changes in psychophysiological performance through the targeted use of stressors, reproducible test conditions were created that realistically simulate essential elements of a work environment (simulated field tests under standardized laboratory conditions). Detailed requirement profiles for test scenarios and the necessary studies were drawn up in collaboration with experts of high operational experience. Key findings from the Austrian Armed Forces' research projects "HeatStress" and "Physiological Load of Explosive Ordnance Disposal Personnel in the Austrian Armed Forces" were incorporated. The following work or investigation scenarios have been defined for the CBRN defence troups: (i) decontamination (decontaminate vehicle, remove protective suit, deco tub, etc.); (ii) CBRN reconnaissance (approach march, sampling, source separation, spraying, etc.); (iii) urban search & rescue (use recovery equipment, transport paramedic stretcher, etc.).

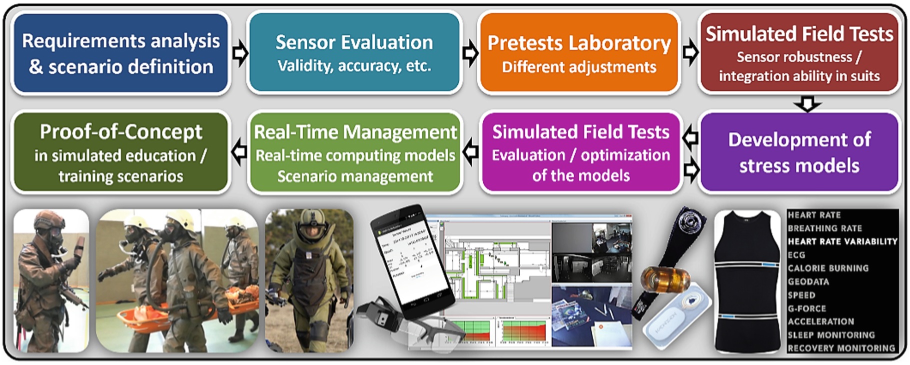

Fig. 1. Graphical overview of the project workflow.

A large number of portable commercial sensor systems (COTS sensor solutions) are now available on the market. Unfortunately, it is difficult to assess the performance of these COTS solutions, since there is usually insufficient information regarding the validity of the measurement data or the algorithms used [1]. An extensive evaluation of potentially usable sensor technology was conducted as part of the project and is currently ongoing. This will be followed by an extensive pre-test to configure the data acquisition in sports science laboratories, initially in reduced military adjustment with sports students, to test the existing "QUS-Smart Clothes" solution in combination with selected additional sensors, according to the necessary operational robustness and to obtain baseline data. Subsequently, stress tests within the Military Medical Center lab of the Austrian Army in military functional clothing (CBRN or bomb protection suit) will be carried out under controlled simulated stress conditions. The sensor system will be evaluated with regard to its operational capability in the functional clothing. Based on these results, the sensor setup will be defined and tests with a concrete, realistic application scenario will be carried out under controlled, simulated application conditions (simulated field tests) with a small number of test persons. These tests will be used for a first development of "expert load models". In a further step, extensive investigations will be carried out within the framework of a study concept involving a larger number of test subjects in simulated, practice-oriented and standardized process scenarios. Here, statistically relevant measurement data will be collected, which on the one hand will serve to validate the developed expert stress models and on the other hand will form the basis for machine-learned models.

4 Wearable Sensors

The main sensor-equipment within this project will be the QUS smart shirt solution. Based on this smart shirt product (see Fig. 2) which is already used extensively in competitive sports, empirical values from many sports are at disposal. Approaches that have a direct reference to the military load scenarios as well as a near-real-time analysis of the measurement data of the different sensors are development goals in this project. Based on the requirements from the application scenarios and the results of the sensor evaluation, additional sensor systems are selected as necessary extensions to the smart shirt sensor technology. Sensor extensions for the smart Shirt solution will be developed as part of the project development (see Table 1). This integration of additional sensor technology and the necessary communication modules will enable better usability in military deployment scenarios, especially in combination with protective equipment and combat suits.

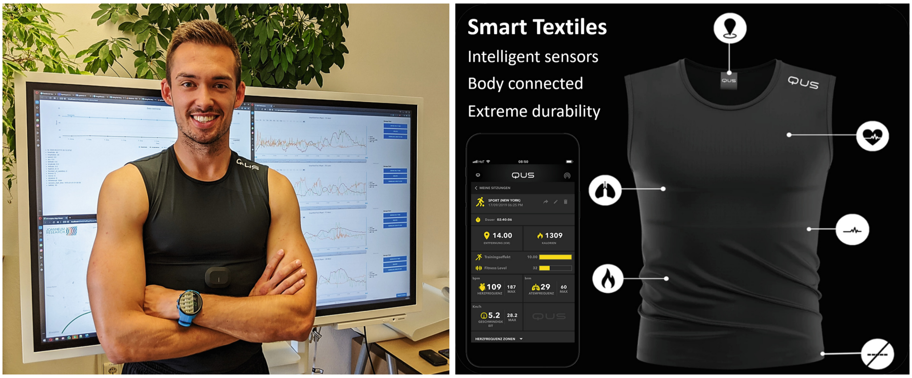

Fig. 2. QUS smart shirt solution with bio-signal visualization in the background

A key innovative objective of this project is the integration of a sensor setup that enables individual heat stress analyses and recognizes critical developments in the water and electrolyte balance. As a consequence, severe stress situations are detected at an early stage. Additionally, this will allow decision support in determining working hours and breaks. The following table provides an overview of the relevant sensor technology that is available in the smart shirt and also shows sensor technology that is available for laboratory tests.

Table 1. Overview of wearable sensors.

Parameters	Measurement	QUS smart textiles	Lab sensors
Cardiovascular strain	HR, HRmax, ECG, breathing mechanics	QUS smart textiles	
Metabolic strain	Lactate, glucose		LOC-sensor
	Aerobic /anaerobic threshold	QUS smart textiles	
Heat strain	Core body temperature, body surface temperature, WBGT	Prototype under development	temperature pill, temperature patch,
Muscular strain	Muscle activity, oxygen saturation		EMG sensor, PPG sensor
	movement dynamics	QUS smart textiles	
Cognitive and affective strain	HR, HRV	QUS smart textiles	
	EDA, eye-tracking		Eye-tracking glasses
Fluid balance	Quantitative sweat measurement	prototype under development	Sweat patch
	Qualitative sweat analysis		LOC sensor

To achieve high acceptance levels for body worn sensors, good wearing comfort is essential. Results from [7], suggest that devices placed on or around the upper arm, the hip, or the shoe will be preferred over devices worn around the wrist or on or around the chest in a military context. Investigations into wearing comfort are therefore an important aspect in the project and different positions of additional sensor solutions will be tested.

5 Project Modules

Figure 3 shows an overview of the main modules which will be carried out within the VitalMonitor project.

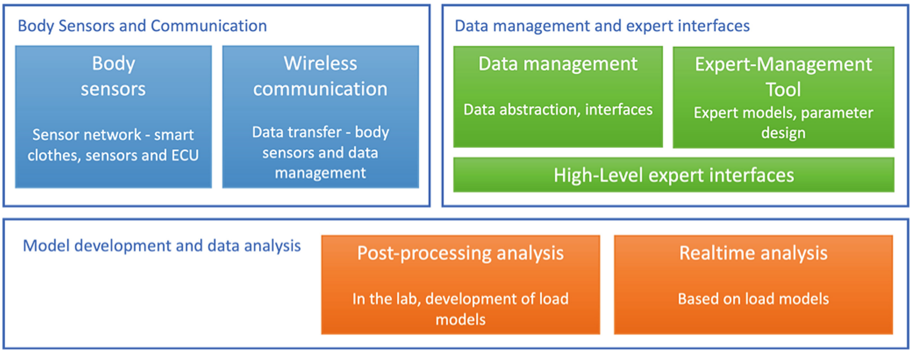

Fig. 3. Graphical overview of the VitalMonitor project modules.

Secure data access, efficient management and clear visualization are crucial for the system. Therefore a "central data ware house" supporting real-time communication and synchronization, data reprocessing as well as providing input/output interfaces has been implemented. The data warehouse including a non-relational database with a flexible storage schema can be set up directly on location on a field laptop, for example. Its primary use is to record timestamped (bio-)signals, store post-processing results and to hold field trial relevant meta data. In order to guarantee a common time base for all sensors, it can interface with a network time protocol server. Depending on the use case, datagrams are exchanged either through UDP or TCP sockets, with the former cutting latency by omitting transmission control. Processing modules can connect directly with the database, making statistical analyses possible in real time as well.

On top of the underlying data warehouse and communication modules a two-fold interactive visualization and management interface will be implemented: (i) an expert interface for data assessment and iterative development of physiological models and (ii) a high-level interface showing use-case specific information only. The expert interface will show sensor data streams (low-level data) together with model-based analysis results (high-level data) in a graphical interface as a basis for model development, verification and optimization. Based on an "Expert-Management-Tool" the entire data-flow from raw data acquisition to inference will be made accessible to enable data labelling and model parametrization based on expert know-how. Further, a high-level interface to visualize analysis results and high-level data for continuous assessment of the soldiers will be provided. Individual physiological parameters, indicators, alerts, are made visible in a graphic interface for the instructor/trainer/medical staff as a basis for continuous assessment and potential intervention. The interface will be adaptable in terms of expert-level/roles, sensor-setup, physiological parameters and can therefore be adapted to the special requirements in various military scenarios.

6 Conclusion and Outlook

Innovative biosensor technology, which is currently available on the commercial market, enables the monitoring of physiological parameters during physical strain and thus basically also during different military deployment scenarios. A targeted use for military tasks, which provides soldiers, executives and medical personnel with meaningful, real-time situation-relevant information, requires an intelligent analysis of the sensor data. These analysis methods take into account, on the one hand, the load characteristics of the operational scenarios and, on the other hand, the individual fitness and stress situation of the persons. As part of the VitalMonitor project, physiology based methods and algorithms are developed on the basis of extensive tests as well as laboratory and field trials using powerful biosensors, which enable the derivation of reliable, supporting information for military training, exercise and deployment scenarios. In order to achieve a high level of acceptance among soldiers for a body worn sensor system, usability tests are very important part of the project.

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Multimodal Measurements, Artificial Intelligence and Mental Structure

A Database for Cognitive Workload Classification Using Electrocardiogram and Respiration Signal

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Abstract. Cognitive workload is a critical factor in determining the level of attentional effort exerted by users. Understanding and classifying cognitive workload is challenging as individuals exert varying levels of mental effort to meet the task's underlying demands. Twenty-six participants (12M, 14F, Mean = 22.68 ± 5.10) were exposed to two different tasks designed to induce low and high cognitive workloads. Subjective and objective measures were collected to create a novel, validated multimodal dataset for cognitive workload classification. Participants' perceived workload was collected using the NASA-TLX. Electrocardiogram (ECG) and Respiration (RR) data were collected to extract the Heart Rate Variability and Respiration Rate Variability features. Four machine learning algorithms were utilized to classify cognitive workload levels where AdaBoost classifier achieved the highest Leave-One-Subject-Out Cross-Validation accuracy, and F1-Score of 80.2%, 80.3% respectively. This is the first publicly available dataset with ECG, RR and subjective responses for cognitive workload classification.

Keywords: Cognitive workload classification · Machine learning · Multimodal dataset

1 Introduction

Cognitive workload can be described as the level of measurable mental and physiological effort and demand that occurs while performing one or multiple tasks. Researchers have observed that high or deficiently low levels of cognitive workload have a negative impact on the task performance and their health. Hence, it's crucial to monitor a user's cognitive load during a task to improve their task performance and health. The three validated and common methods to measure cognitive load are: subjective responses using surveys, measuring performance on primary and secondary tasks (number of errors, response time, etc.), and analyzing physiological responses [1]. It's important to note that the first method is mainly used as the ground truth to comprehend what users perceive as their

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current cognitive load. In contrast, the second and third tools act as real-time objective measures of the user's cognitive workload[1].

Cognitive workload is associated with a change in neurophysiologic activities, and prior studies have noted cognitive workload has a distinct effect on human physiology. One of the main components of the neurophysiologic system is the autonomic nervous system (ANS), which consists of two major systems: the sympathetic and the parasympathetic system [2]. Prior studies have observed cardiovascular activity and respiration (RR) are critical indices that can explain the balance or imbalance in ANS as a result of cognitive workload [3–12].

The recent advances in machine learning allow researchers to utilize various machine learning algorithms to classify a user's cognitive workload and assist in decision-making in real-time using physiological measures. This research focused on exposing participants to high and low cognitive load inducing tasks and collecting subjective (NASA-TLX) and objective measures (Electrocardiogram (ECG) and RR) to create a novel, validated multimodal dataset for classifying cognitive workload. To our knowledge, this would be the first publicly available dataset with ECG and RR signals and subjective responses for cognitive workload classification. This dataset could help other researchers to validate their machine learning algorithms for cognitive load classification. Moreover, our algorithms can be potentially applied to the healthcare and manufacturing sectors to monitor a physician's/employee's cognitive load.

2 Background

Prior studies have used various physiological measures, including ECG, RR and eye metrics, to comprehend user's cognitive load and task difficulty. Among the ECG signals, Heart Rate (HR) and HRV (Heart Rate Variability) are the most commonly used metrics. Researchers have reported a positive correlation between HR levels, cognitive load and task difficulty [3–5]. Additionally, time domain and frequency domain metrics of HRV have been investigated to comprehend the mental workload. Studies have consistently observed a decrease in the time domain measures and an increase in the frequency domain metric (LF/HF ratio) while performing tasks that require higher mental demand [7, 8]. These observations suggest an increase in sympathetic activity, also known as the fight or flight response [6–10]. Similarly, respiration rate derived from RR data represents the rate at which a person breathes per minute, has been reported as a crucial determinant of cognitive workload where respiration rate increases as the complexity of tasks increases [11, 12].

Advances in machine learning have piqued the interest in using algorithms to classify cognitive workload based on physiological response in recent years. In the work of Magnusdottir et al. (2017), participants engaged in a three-level Stroop task that consisted of a set of words of five colors. Multiple cardiovascular data metrics were recorded during all tasks, and a subject-dependent SVM was used to predict cognitive workload achieving an average misclassification rate of 20.44% [13].

In another study, participants performed NASA's MATB-II pilots multitasking tasks while their Electroencephalography (EEG) data were collected. EEG channels were

1 https://gitlab.com/hilabmsu/cw-database.

used to train Neural Network classifiers to distinguish the cognitive workload where the accuracy ranged from 46–90% based on the EEG channels [14].

A recent study collected various physiological indices, including HRV and electrodermal activity (EDA), from sixteen participants while they performed three different tasks: a psychomotor vigilance task, an auditory working memory task (the n-back paradigm), and a visual search (ship search). Using all the possible sets of the eight indices of HRV and EDA, several machine learning algorithms were trained (k-NN, LSVM, GSVM, LDA, QDA, M-QDA) to achieve the highest leave-one-out accuracy of 66% for cognitive workload classification using a kNN Bayes classifier [15].

Finally, another study utilized a search and rescue with drones scenario to induce different cognitive workload levels while various physiological signals, including ECG, PPG, RSP, and skin temperature, were collected from 24 participants. The collected biosignals were used to train several machine learning classifiers such as LogReg, DTC, k-NN, LDA, GNB, SVM, and XGB and the highest average accuracy for cognitive workload classification of 89% was achieved using an XGB algorithm with a 10-fold cross-validation learning curve [16].

3 Study Design and Database

3.1 Participants

Participants of this study included 26 students (12M, 14F, Mean = 22.68 ± 5.10) attending Montana State University. In accordance with the university policies associated with COVID-19 restrictions, participants were recruited by convenient sampling and participation in the study was voluntary. All participants included in the study signed a consent form and were subject to the experiment protocols approved by University's Institutional Review Board under IRBNO: AK030220-EX. There were no dropouts in this study, and participants were compensated with a $25 Amazon gift card for their time.

3.2 Apparatus

The two tasks which aimed to induce cognitive load were presented on a Dell screen with 1680 *1050 resolution. Participants were seated in a rigid but comfortable posture with feet placed flat on the floor in a quiet room with normal light and temperature. The physiological data were collected using the clinically validated Biopac® MP160[2] system, and the specific device was selected as it is portable, non-obtrusive and allowed for modular data acquisition. The ECG and RR signals were collected at a sampling rate of 1000 Hz.

3.3 Study Protocol

To induce the two levels of cognitive workload, the validated NASA MATB II application was utilized [20]. The study was conducted in the Human Interaction lab at Montana State University. Prior to exposing the participants to the cognitive workload tasks, they were

[2] https://www.biopac.com/.

outfitted with sensors that captured the physiological signals. For collecting the ECG data, we used a 3-lead chest configuration, and for the respiration data, a respiration belt that went around the chest was utilized. After placing the sensors, the real-time signals were checked, and initial quantitative measures were conducted during a five-minute period in which the participant remained silent and seated in a comfortable posture at the testing station. No participatory tasks were administered during this time. Following the baseline, the participants performed a practice trial to familiarize themselves with the nature of the task and eliminate the potential for participatory error associated with a lack of confidence with the interface or the need to learn fundamental tasks extemporaneously. Once the participants were comfortable with the MATB II application, they were asked to rest for three minutes to control for the effect of training on physiological data [17].

As mentioned previously, the participants were exposed to two different cognitive workload tasks. The order of the tasks was counterbalanced to control for order effects. Upon completing each task, the NASA-TLX questionnaire appeared in a full window and the participants used the sliders to select the rating values for the six subscales of the questionnaire. Further, between each task, the participants were given a three-minute rest period to control the carry-forward effect of one experience on the physiological data. During the experience and the rest period, one of the researchers continuously monitored the physiological data to assure that they were collected and transmitted without any issues. The low cognitive workload task lasted for 15 min and consisted of a tracking (primary) task. During this task, the participants had to use a joystick to keep a moving target in the center of an inner box presented on the desktop screen. However, for the high cognitive workload task, the participants were asked to perform two tasks simultaneously. The primary task is the task of interest (tracking task), and a secondary task is performed alongside the primary task. We utilized a communication task as the secondary task during which participants listened for messages every 30 s (like air traffic control requests) and were required to adjust the frequency of a specific radio.

3.4 Ground Truth

There is a direct correlation between tasks required to achieve a goal and the amount of workload imposed on the subject. Albeit the same task can result in significantly different workload levels due to individual differences (experience/expertise/perception); Surveys can capture these individual variations. To verify the taxonomy of cognitive workload, we utilized NASA-TLX to collect participants' perceived workload. Significant (p-value < 0.01) higher differences were found in reported values of the TLX-Score while comparing High to the low cognitive workload task using paired t-test. Similarly, participants reported significantly (p-value < 0.01) higher mental demand, temporal demand, and effort during the high workload task. No significant differences were found in the reported values of physical demand and frustration level between the two tasks and thus were not considered. Moreover, the tracking task score was significantly (p-value < 0.01) lower during the high workload task, validating the task's capability to generate a higher cognitive workload. Based on these findings, we used NASA-TLX values as ground truth to create two class labels - a) low cognitive workload or b) high cognitive workload.

4 Cognitive Workload Classification

4.1 Feature Extraction and Selection

The first step was to segment each state in windows to extract the HR, RR, HRV and RRV features for every participant. Each cognitive workload level was segmented using a window size of five minutes (300,000 data points) data points with a sliding window of 30 s corresponding to 30,000 data points. To extract the ECG signal features, we first detected the Q wave, R wave, S wave (QRS) complex for each window and then derived the time series metric of RR interval data [18]. Next, we performed a power spectrum analysis using wavelet transformation, a time-frequency analysis method to scale the decomposed ECG signal into different frequency band signals [19]. To derive the respiration rate metrics, we used a low-pass signal filtering and the detection of zero-crossings of the filtered signal on the respiration signals. Further, to obtain the iterative breath interval (IBI), we calculated the respiration rate variability (RRV) by recording the time stamp at the peak of each breath pulse and then subtracted the subsequent peaks to obtain the breath-to-breath (BB) interval [20]. Finally, the quality, scaling, and correlation properties of the ECG and RR signals were assessed to extract the nonlinear-domain features.

After deriving features from the ECG and RR data, we investigated four feature sets for cognitive workload classification. The first feature set included only the HR and HRV features (time-, frequency-, nonlinear-domain) extracted from the ECG signal. In the second feature set, we utilized respiration rate and RRV features (time-, frequency-, nonlinear-domain) extracted from the respiration signal. The third feature set was a combination of feature set one and two and included sets of features that contained all the features extracted from the ECG and respiration signal. Finally, in the final feature set, we included specific features from time and frequency domain metrics of HRV and RRV based on literature as these metrics have been found to classify cognitive workload levels.

4.2 Classification Algorithm

One of our main aims is to develop machine learning algorithms that can reliably detect higher cognitive workload levels among the participants. We evaluated the performance of four different machine learning algorithms Random Forest (RF), Logistic Regression (LogReg), Linear Support Vector Machine (L-SVM), and AdaBoost (AB) with decision tree as base classifiers for cognitive load classification using the different subsets of features as discussed in the previous section. The grid-search approach was used to find the optimal hyper-parameters for each classifier. Depending on the selected model, we chose a combination of a specified set of hyperparameter values to find the optimal values for each machine learning model. To evaluate the performance of the classifiers, we trained the models and then performed Leave-One-Subject-Out (LOSO) cross-validation where one participant was randomly selected for testing purposes while the other participants were used for training the model [15]. This process was repeated until all the participants were used as a test dataset. We calculated the accuracy and F1-score for each participant to evaluate the model performance.

5 Results and Discussion

As mentioned in the previous section, evaluation was performed using each of the four machine learning algorithms. We created a setup where each machine learning model ran four times to report the mean and the standard deviation LOSO cross-validation accuracy and F1-Score for each feature set. Depending on the input feature set, the machine learning models achieved accuracies ranging from 60–80%, while F1-score ranged between 52–80%. On the first feature set, which utilizes only HRV features, the accuracies and F1-Scores of the models range from 59–68.6% and 52–67%, where the highest accuracy and F1-Scores were achieved using the AB classifier. The rest of the three models did not vary significantly on predicting the two cognitive workload states. In the next feature set, which utilized only RRV features, we achieved accuracies and F1-Scores ranging from 76–78% and 77–80%, where all the algorithms had a very similar performance on classifying the two states, with RF slightly outperforming the others. On the feature set, which utilizes both HRV and RRV features, the accuracies varied between 76% and 80% and F1-Scores between 75% and 80%. Here, the AB classifier achieved the highest performance score while the other classifiers behaved very similarly. Finally, on the fourth feature set, we achieved accuracy between 72–77% and F1-Scores between 70–75% by manually selecting features that play an important role in the balance of the ANS. Table 1 below represents the accuracy and F1-scores achieved using four algorithms with four different feature sets.

Table 1. Accuracy and F-1 scores of the algorithms with four different feature sets (1: HRV only, 2: RRV only, 3: HRV and RRV, 4: Manual Feature Selection).

	LogReg	RF	L-SVM	AB
	Accuracy ǀ F1-Score	Accuracy ǀ F1-Score	Accuracy ǀ F1-Score	Accuracy ǀ F1-Score
1	63.4 ± 24.5ǀ59.5. ± 28.7	59.8 ± 23.6ǀ52.5 ± 30.3	61.1 ± 24.5ǀ54.7 ± 29.8	68.6 ± 21.3ǀ65.9 ± 26.1
2	78.1 ± 22.4ǀ78.1.4 ± 21.4	78.1 ± 30.1ǀ80.1 ± 16.7	77.1 ± 22.9ǀ76.7 ± 22.1	76.8 ± 21.2ǀ78.1 ± 18.6
3	75.2 ± 24.8ǀ75.8.4 ± 23.1	75.1 ± 21.4ǀ75.1 ± 20.4	75.5 ± 24.4ǀ75.9 ± 3.8	**80.2 ± 20.1ǀ80.3 ± 21.1**
4	73.9 ± 24.3ǀ73.8 ± 23.2	76.4 ± 22.8ǀ75.1 ± 20.4	76.9 ± 15.3ǀ72.1 ± 23.9	72.3 ± 22.1ǀ70. ± 25.2

The comparison of the classification models clearly shows that AB allows achieving the highest accuracy, F1-Score and less variation among the participants than the other models for the three sets of features. It can be noted that only for the feature set that uses only RRV features, all the other models outperformed AB. Additionally, we observed that the integration of all physiological features (HRV and RRV) slightly increased the models' performance calling further investigation to determine the importance of the HRV and RRV variables in classifying the cognitive workload levels. Finally, we observed that using only HRV features achieved considerably lower classification scores than results obtained using only RRV features. This observation suggests that features extracted from the respiration signal can be more informative in classifying the cognitive workloads and could be potentially used as the sole input for cognitive workload classification.

6 Conclusion

This study focused on developing a validated multimodal dataset for cognitive workload classification. Participants were asked to perform two different cognitive workload tasks that aimed to induce two levels of cognitive loads. We evaluated the capability of four machine learning algorithms to classify the cognitive workload using four different feature sets of physiological signals. Our results indicate that both HRV and RRV physiological measures are good predictors of cognitive workloads, with RRV data providing more critical information for cognitive load classification.

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Using BERT Model for Intent Classification in Human-Computer Dialogue Systems to Reduce Data Volume Requirement

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Abstract. User-intent classification is a sub-task in natural language understanding of human-computer dialogue systems. To reduce the data volume requirement of deep learning for intent classification, this paper proposes a transfer learning method for Chinese user-intent classification task, which is based on the Bidirectional Encoder Representations from Transformers (BERT) pre-trained language model. First, a simulation experiment on 31 Chinese participants was implemented to collect first-handed Chinese human-computer conversation data. Then, the data was augmented through back-translation and randomly split into the training dataset, validation dataset and test dataset. Next, the BERT model was fine-tuned into a Chinese user-intent classifier. As a result, the predicting accuracy of the BERT classifier reaches 99.95%, 98.39% and 99.89% on the training dataset, validation dataset and test dataset. The result suggests that the application of BERT transfer learning has reduced the data volume requirement for Chinese intent classification task to a satiable level.

Keywords: User-intent classification · Human-computer dialogue system · Pre-trained language model · Transfer learning

1 Introduction

1.1 Intent Classification

In the 1950s, Alan M. Turing proposed "the Turing Test", in which a human and a computer interact utilizing natural language. Since then, human-computer dialogue systems have been considered as one of the most essential components of artificial intelligence (AI) systems. A typical human-computer dialogue system consists of 5 modules, namely speech recognition, natural language understanding, dialogue management, natural language generation and text to speech [1]. Intent classification means classifying input utterances into a set of pre-defined categories. It's an essential sub-task in the natural language understanding module.

Intent classification is defined as a short-text classification task. Current approaches for intent classification mainly include bag-of-words in combination with machine learning and deep learning methods such as Long Short Term Memory (LSTM) networks. Deep

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learning methods, due to their superior performance on open-domain text classification tasks, has become a state-of-art method for intent classification tasks [2]. However, deep learning methods require a very large volume of data. And the application of deep learning models in intent classification tasks has encountered the difficulty of insufficient data [3].

Transfer learning is capable of reducing the data volume requirement for downstream deep learning tasks. In 2011, collebert et al. Successfully constructed a pre-trained model which can complete tasks such as text marking, word segmentation, named entity recognition, semantic tagging and so on [4]. In 2015, the RESNET pre-trained model showed its powerful ability on the classification task of Imagenet competition [5]. Hence, transfer learning began to cut a striking figure. In recent years, the academic community has been putting forward new and more complex pre-training models [6, 7, 8, 9, 10, 11, 12, 13].

1.2 The BERT Pre-trained Language Model

The Bidirectional Encoder Representations from Transformers (BERT) model is a Transformer-based pre-trained language model announced by Google Brain Team in 2018 [9]. It has remarkable performances on 11 natural language processing tasks of the General Language Understanding Evaluation Benchmark (GLUE).

The BERT model was trained on Wikipedia in the form of Semi-supervised learning. The training data for BERT are sequence pairs with masks that covers random words in the text. There are two training targets for the BERT model: one is predicting masked words, and the other is predicting if the 2 sequences from input data have context relations. The training process enables the BERT model to understand input text from both word-level and sentence-level, allowing it to adjust to various downstream language processing tasks.

Figure 1 shows a simplified process of the BERT model transfer learning process, including pre-training and fine-tuning. During pre-training, the model is trained on vast amounts of data and forms an understanding of words collocation and sentences combination. These understandings are saved as inheritable parameters. When fine-tuning, the model is re-trained for a new task. Resulting from the inherited parameters, the model can reach an ideal status with a limited amount of new data.

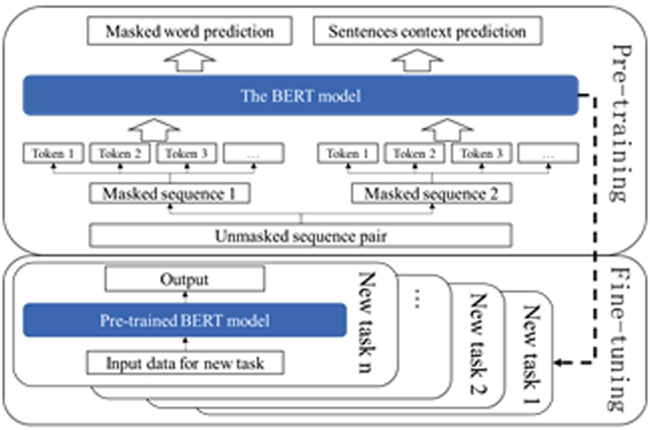


Fig. 1. Pre-training and fine-tuning process of the BERT Model.

2 Methods

2.1 Data Collecting

Voice assistants are the most significant form of human-computer dialogue systems. According to eMarketer's business report [14], voice assistant use is growing among all age groups, from children to seniors. The most popular devices are smartphones and smart speakers. And the cardinal tasks given to human-computer dialogue systems are information retrieval and smart devices controlling. Besides, most people are hoping to chat with their devices as they do with a human. In all, there are 3 main categories of user intents, namely task completing, information requesting and chatting.

According to the report, we prepared 10 human-computer interaction simulation scenarios for each of these 3 categories. As shown in Table 1., there were 30 scenarios in total, all of which were based on real-life human-computer conversations.

Table 1. 30 human-computer interaction Scenarios.

ID	Task completing	Information requesting	Chatting
1	Ask to play music;	Request information about one artist;	Talk about the music
2	Ask to command intelligent equipment;	Request information about the Weather;	Talk about the weather;
3	Ask to book traffic ticket;	Request information about traffic status;	Talk about traffic;
4	Ask to book a hotel;	Request information about one hotel;	Talk about one hotel;
5	Ask to book a movie ticket;	Request information about one movie;	Talk about movies;
6	Ask to translate a sentence to another language;	Request information about one language or country;	Talk about one language or country;
7	Ask to call a contact;	Request information about contacts;	Talk about a person;
8	Ask to set a reminder;	Request information about reminders;	Talk about daily life;
9	Ask to set an alarm;	Request information about time;	Talk about time management;
10	Ask to book a restaurant;	Request information about a restaurant;	Talk about a restaurant;

In the experiment, 31 Chinese participants between 15 and 63 ages were recruited. Each participant was randomly given 9 of these scenarios, 3 from each category. They were asked to speak to an intelligent speaker. Their words were saved as text data. Since the trigger word used to wake up the intelligent speaker has nothing to do with the user intent, it was removed from the text. At last, a total of 279 utterances were collected.

2.2 Datasets Construction

Insufficient data is a common problem in neural network training. Researchers have various approaches to implement data augmentation. In the field of natural language processing, there are vocabulary substitution, back translation, text surface conversion, noise injection, case cross expansion, grammar tree, text mixing and so on.

As is shown in Fig. 2, back translation means translating text data into several other languages and then translate it back to the original language [15]. It is one of the most important text data augmentation techniques. Utilizing back translation, researchers can expand their text data by dozens of times.

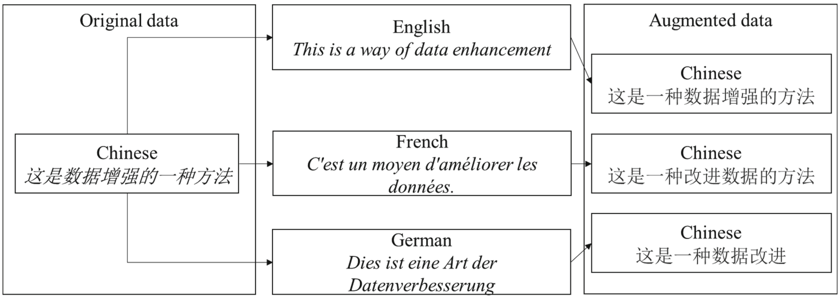


Fig. 2. Back translation.

In this study, we used Baidu translation API (http://api.fanyi.baidu.com/api/trans/vip/translate) to translate our Chinese text data into English, Cantonese, Japanese, Korean, French, Spanish, Thai, Arabic, Russian, Portuguese, German, Italian, Greek, Dutch, Polish, Bulgarian, Estonian, Danish, Finnish, Czech, Romanian, Slovenian, Swedish, Hungarian, Vietnamese and then translate them back to Chinese, expanding our data by 26 times. For c_i in set C, there was $c_{i1}, c_{i2}, c_{i3}, \ldots, c_{i25} \in C'$. New dataset $S = C \cup C' = \{s_1, s_2, s_3, \ldots, s_{7254}\}$. We labeled utterances of "task completing", "information requesting" and "chatting" with $l \in L = \{\text{"0"}, \text{"1"}, \text{"2"}\}$. On the premise of ensuring data balance, we randomly split dataset S in to training dataset $T = \{t_1, t_2, t_3, \ldots, t_{4306}\}$, $V = \{v_1, v_2, v_3, \ldots, v_{1076}\}$ and test dataset $X = \{x_1, x_2, x_3, \ldots, x_{1872}\}$. For every data, there was a text w and its label l.

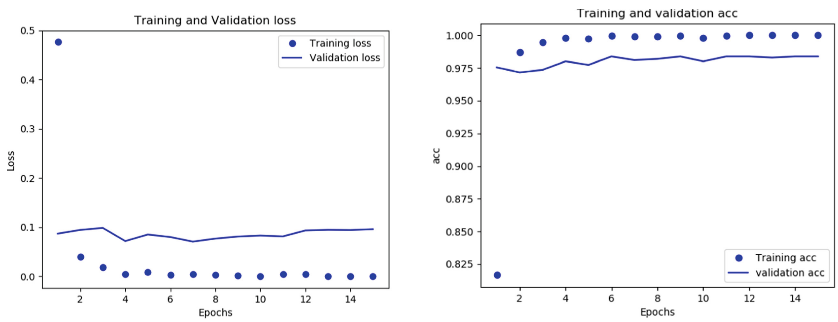
To feed our data into the BERT model, the length n (sequence_length = n) of text w must be standardized. The text data w were cut into the same length n, each word in w was represented by a token in a dictionary D, unified words will be marked as *unused*. The BERT model has a dictionary D of 21129 words, each word can be mapped to a vector v in the BERT model. After this step, we had our *train_dataset*, v*alidation_dataset* and *test_dataset* ready.

2.3 Re-training the BERT Model

For the BERT model to adjust to the intent classification task, it needs to be re-trained on *train_dataset*. This step will give new parameters to the BERT model. For the BERT model to process our short text data, we defined *sequence_length* = *128*, number of text per input *batch_ size* = *24*, *dropout* = *0.1* and *learning_rate* = *2e-5* [16]. The model was trained on *train_dataset* for 15 epochs. After every epoch, all parameters were saved, and the model was then tested on *validation_dataset* for its *loss* and *accuracy*. At last, according to the training results, the best parameters will be loaded to the final model, which will be tested for generalization ability on *test_dataset*.

3 Results

Figure 3 shows the loss and accuracy of the model after every epoch, the model began to converge when *epoch* = *7*. Therefore, we chose the model when *epoch* = *7* as the final trained intent classifier. At this point, the model had *loss* = *0.0043*, *accuracy* = *99.95%* on *train_dataset* and *loss* = *0.0935*, *accuracy* = *98.39%* on *validation_dataset*.



a. loss b. accuracy

Fig. 3. Loss and accuracy on *train_dataset* and *validation_dataset*.

Finally, the model was tested for generalization ability on *test_dataset*. We also collected 104 new non-augmented utterances as a *raw_test_dataset*. The resulting accuracy on *test_dataset* and *raw_test_dataset* was 99.89% and 99.04%. The results suggest that the model can complete the Chinese intent classification task commendably.

4 Conclusions

Human-computer dialogue systems is a crucial concern in the era of artificial intelligence. Focusing on the intent classification task in Chinese human-computer dialogue systems, the following works have been done:

(1) Collecting Chinese intent utterances data;
(2) Constructing Chinese intent classification dataset;
(3) Fine-tuning the BERT model for Chinese intent classification task.

Training robust deep learning models on a small dataset is a challenging task. This is why machine learning methods such as Multinomial Naive Bayes Algorithm and Support Vector Machin has been in a dominating position for utterance intent classification tasks. This study puts forward a deep learning method based on the BERT model transfer learning to reduce data volume requirement for Chinese utterance intent classification.

This study shows that the application of the BERT pre-trained language model can reduce the data volume requirement of Chinese intent classification tasks to a relatively low level with high classification accuracy. This study also gives an example of applying pre-trained language models in short text classification tasks, showing detailed steps form data collection to model fine-tuning.

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Human-Machine Learning with Mental Map

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Abstract. Many cognitive processes can be represented as a graph that is visual and computational. Graph search used to be a classic AI method. Here we present a dynamic graph, called "Mental Map" with a set of timestamps, nodes, edges, attributes, and operators for extracting experts' knowledge and incorporating other AI models such as Association Rule Learning and Decision Tree. Mental Map is written in Javascript and it can run on any platform that has a web browser. Three case studies are presented: suspicious behavior detection, email phishing, and malware detection in embedded systems. The tool can be used interactively and automatically. Through human-machine collaborative learning, Mental Map provides more explainability and flexibility than prevailing semantic webs and machine learning algorithms.

Keywords: Graph · Semantic web · Human-machine learning · Mental map · Cognitive process · Cognition · Decision tree · Association Rule Learning

1 Introduction

The 19th-century French mathematician Henri Poincaré said: "It is by logic that we prove, but by intuition that we discover." Our cognitive process or mental map can be simplified as a graph, which is visual and computational. A dynamic graph can be represented as a set of timestamps, nodes, edges, and attributes. Graph search used to be a classic AI method [1]. A graph is also a model of learning and memory EPAM (Elementary Perceiver and Memorizer) [2].

Ontologies have received growing attention with the rise of the Semantic Web as a way to provide insight rather than just information [3]. Visualizations can help general users by assisting in the development, exploration, verification, and sense-making of concepts and relationships. However, most existing visual ontologies are static and have limited capacity to expand to real-time or broader applications.

Web-based process tracing tools such as MouselabWEB has been used to model the information acquisition process of decision-makers [4]. Google's Knowledge Graph is a giant step for moving from an information search engine to a knowledge search engine [5]. The Knowledge Graph contains over 500 million objects and about 3.6 billion facts about and relations between these different objects. Furthermore, T-SNE (t-Distributed Stochastic Neighbor Embedding) enables dimensionality reduction that is suitable for the visualization of high-dimensional datasets up to 30 million examples [6].

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In this study, we present a cognitive process model called “Mental Map” which can be used to extract experts’ knowledge and incorporate it with other AI models, such as Association Rule Learning [7] and Decision Tree [8]. Figure 1 illustrates the architecture of the cognitive process model: “Mental Map.”

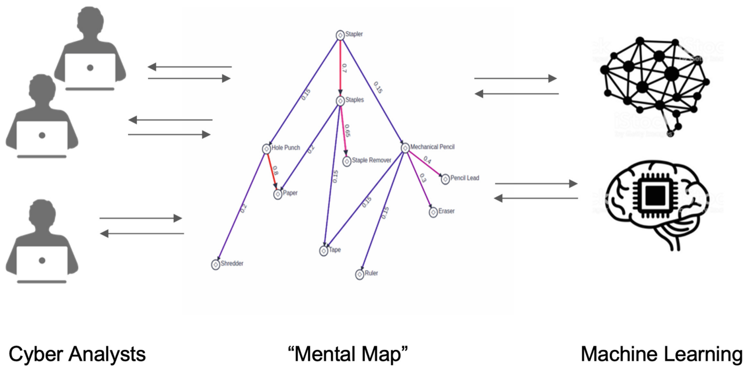

Fig. 1. Mental Maps bridge humans and machines for learning and discovery

2 The Mental Map Model

We have developed a prototype of Mental Map in Javascript. It can run on any platform that has a web browser. It is designed to accept two types of input: 1) manual editing on the screen or 2) automatic processing with JSON data files. Figure 2 shows the editing screen for creating a graph with multiple attributes for nodes and edges. The edges are curved arrows so that they can represent bidirectional connections between two nodes. The editing screen has a setup and file management menu and a pop-up window for entering attributes. The graphs can be saved, loaded, merged, and edited.

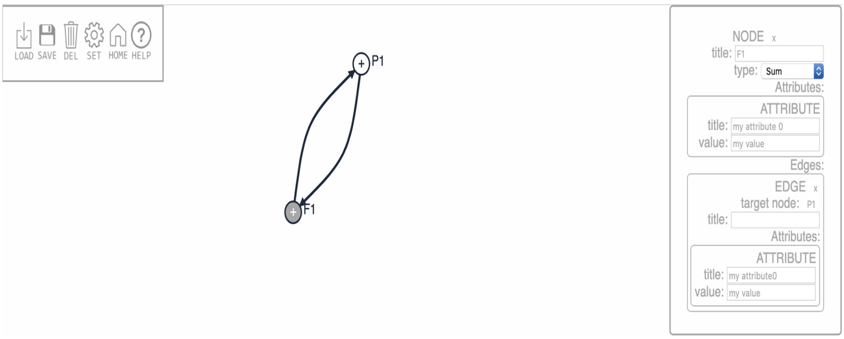

Fig. 2. Mental Map with multiple attributes for nodes and edges

3 Case Studies

Leonardo Da Vinci said: "Simplicity is the ultimate sophistication." Mental Map can represent a variety of cognitive processes, ranging from detecting suspicious behavior in machine code, email spoofing, to malware discovery. We used the Mental Map to extract cybersecurity analytic knowledge from experts. We found the tool is helpful to refine the structure of knowledge. In some cases, it revealed hidden logic or structures behind an expert's intuition.

For example, suspicious behavior detection. The expert started with tracking suspicious behaviors of system calls: creating a process (CP) and self-referenced reproduction (SRR) and other suspicious behaviors: modified key registry and deleted multiple key registries, or failed TCP, etc. From the initial graph, CP and SRR are parallel. See Fig. 3. Then, the expert realized that the two are sequential. Next, the graph was revised to show that the SRR happens before CP. See Fig. 4. The expert was asked to label the links that are associated with suspicious behavior (SB). See Fig. 5. Finally, the expert was asked to order the behaviors. See Fig. 6. Through this process, the expert not only transferred his knowledge to colleagues and students but also encoded his domain knowledge and refined the structure and logic. The recorded graph with multiple attributes can be stored in a JSON file and can be merged with the graphs from other experts easily.

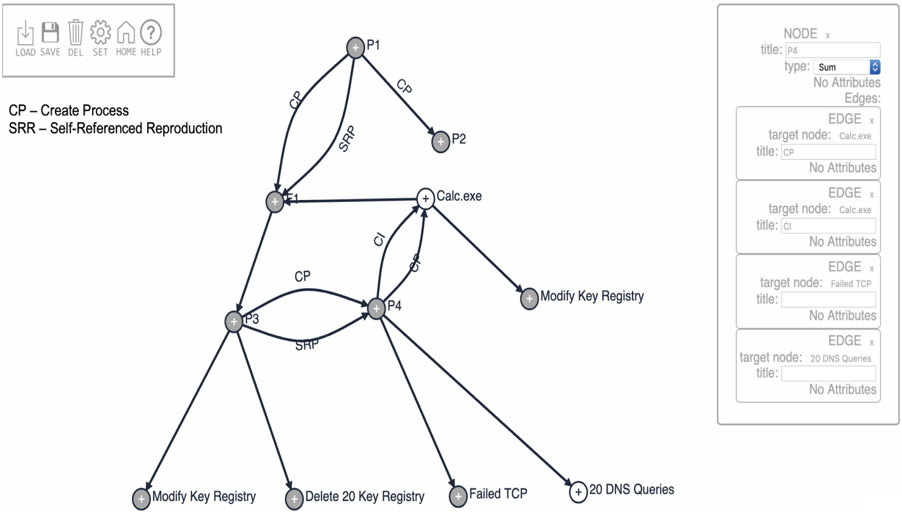

Fig. 3. Suspicious behavior detection in parallelism

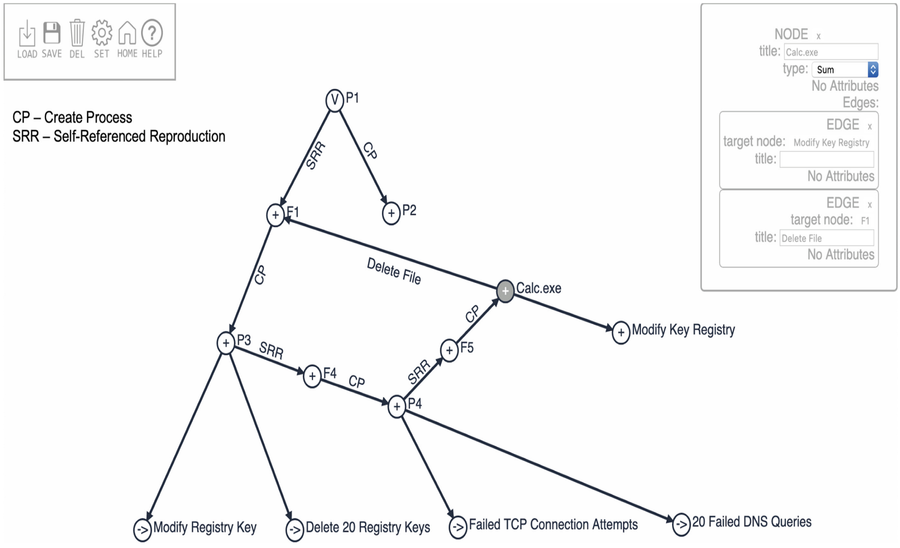

Fig. 4. Suspicious behavior detection in sequential

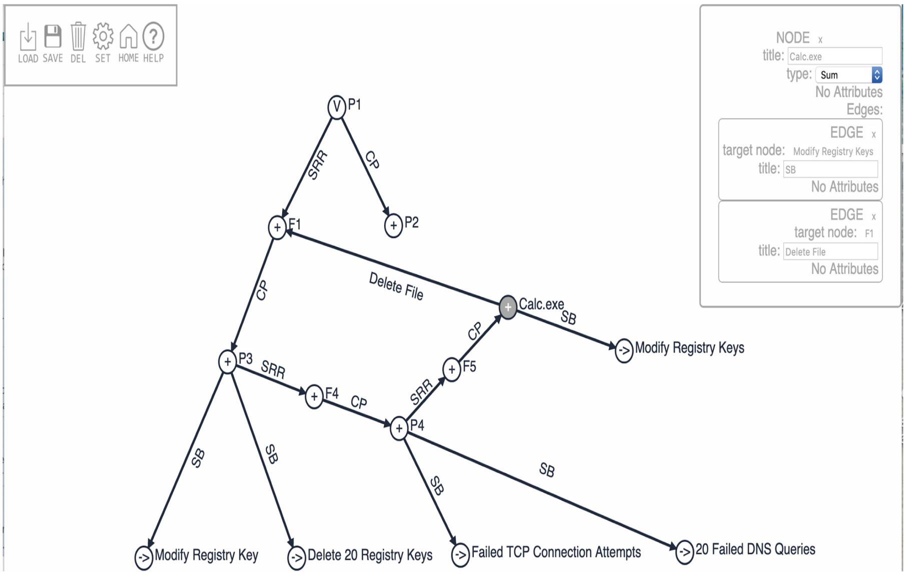

Fig. 5. Suspicious behavior detection with SB scores

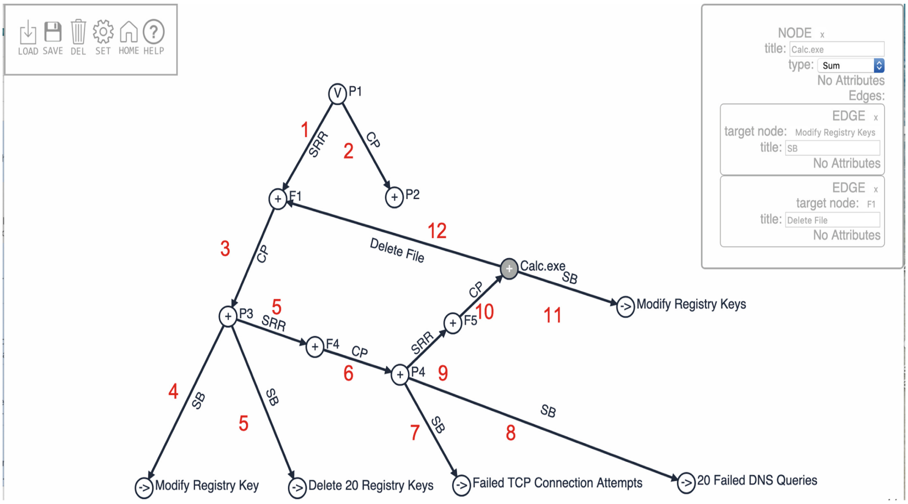

Fig. 6. Suspicious behavior detection with order attributes

We tested a real-world email spoofing detection case. For example, we have the spoofing email sample below, where a hacker pretended to be the Chair of the BME Department with a Gmail account. We interviewed a group of analysts in an Information Security Office. We got the mental Map graph in Fig. 7.

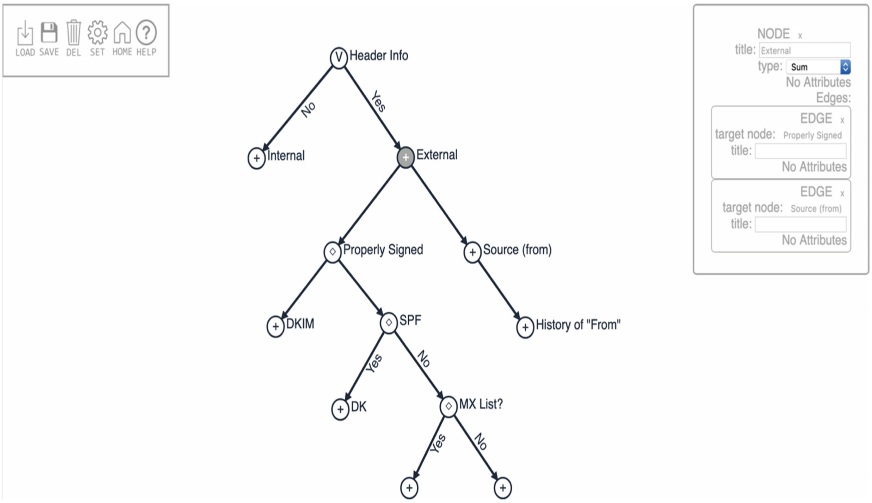

Fig. 7. Email spoofing detection (a reversed vulnerability problem)

Figure 8 shows the Mental Map of the Bitcoin mining malware discovery on the embedded system Raspberry Pi. The graph can be enhanced with attributes such as confidence and cost values. It started from a normal Linux code diagnostic process (blue paths) that led to malware detection and identification (red path). The cognitive process shows how an unknown malware was discovered through suspicious behaviors in terms of CPU performance. It also shows the search strategy: low-cost paths first; and advanced tools later (e.g. packets count or Wireshark). The process also indicates the importance of domain knowledge and related experience during the detection and attribution process.

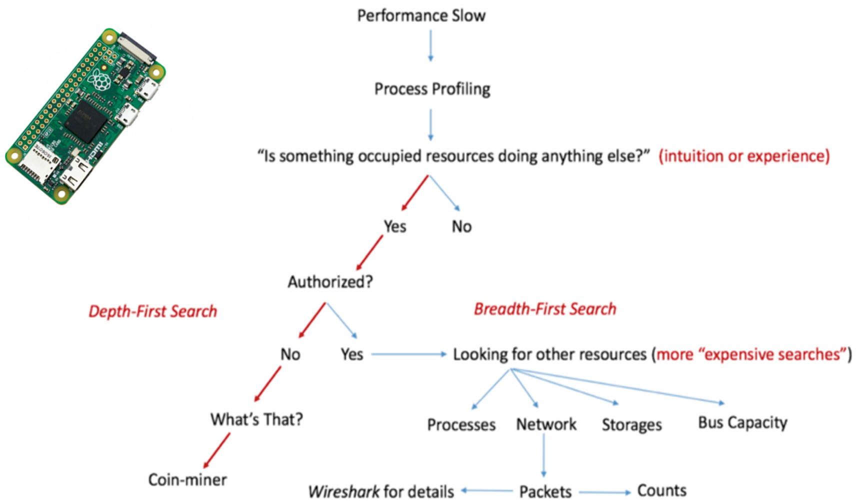

Fig. 8. The search paths that led to the discovery of malware on Raspberry Pi Zero

4 Incorporating Machine Learning Models

The Mental Map can be incorporated in Machine Learning algorithms such as Association Rule Learning and Decision Trees. Association Rule Learning (ARL) has been widely used in recommendation systems such as Amazon. Amazon patented one of the ARL algorithms. The goal of ARL is to determine the most likely next step after a given decision. By assigning the Mental Map graph with frequency attributes on the edges, we can turn the graph into an ARL model. Figure 9 is an example of a graph of a set of office supplies and their interaction frequencies. The graph automatically adjusts the distances between the nodes so that the shorter the links, the higher likelihood it will happen next. The pseudocode is as follows:

```
1. From each node, determine the probability of all other
   nodes occurring
2. Represent the probability [0,1] by both the proximity of
   the node and the temperature of the edge, with shorter,
   hotter nodes representing a higher probability and
   longer, cooler nodes representing a lower probability
```

From Fig. 9 we can see that Hole Punch and Paper are closely related, and Stapler and Staples are next closely related. Relatively, Stapler and Hole Punch are quite distant.

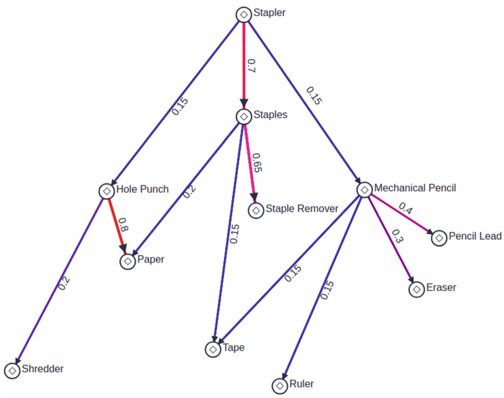

Fig. 9. Association Rule Learning example of the interactions between office supplies

The Mental Map can also be a Decision Tree model by incorporating condition statements at certain nodes. The purpose of the Decision Tree is to graphically display how a complex decision process can be reconstructed. The pseudo-code for a Decision Tree is as follows (Fig. 10).

```
Repeat until all paths are reached:
    1. Add actions linearly
    2. At each condition statement, branch in two separate
       directions, then follow both paths until completion
```

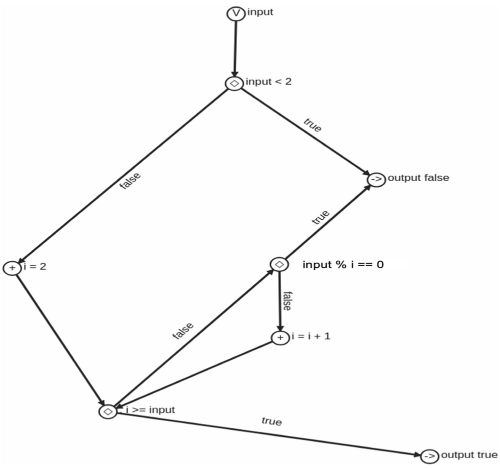

Fig. 10. Example of a Decision Tree by incorporating condition statements in the graph

5 Conclusions

The "Mental Map" consists of a set of timestamps, nodes, edges, attributes, and operators for extracting experts' knowledge and incorporating other AI models such as Association Rule Learning and Decision Tree. Mental Map can run on any platform that has a web browser. From the three cybersecurity case studies, we found it is capable of modeling an expert's cognitive process and reiterating the model with more details and more accuracy. Through human-machine collaborative learning, Mental Map provides more explainability and flexibility than prevailing semantic webs and machine learning algorithms.

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