The relationship between visual website complexity and a user's mental workload: A NeuroIS perspective

Completed research

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Abstract. I report results from an experiment on the relationship between visual website complexity and users' mental workload. Applying a pupillary based workload assessment as a NeuroIS methodology, I found indications that a balanced level of navigation complexity, i.e., the number of (sub)menus, in combination with a balanced level of information complexity, is the best choice from a user's mental workload perspective.

Keywords: NeuroIS, eye-tracking, mental workload, pupil diameter, IS complexity, website complexity, navigation complexity, information complexity

1 Introduction

In this work I report on results from a completed experiment, for which prior research-in-progress results were presented last year on the Gmunden Retreat 2015 [1].
Website/webpage complexity affects a user's mental workload [2], and Huang [3] identified the amount of information and the number of links as important attributes of a website's complexity. The problem from a website design perspective is how to strike a balance between the dilemma of a complex menu structure (a lot of menu links and submenus) but non-complex pieces of information or a non-complex menu structure (with fewer links/submenus) with a high amount of information (more complex). To evaluate this problem researchers need a convenient way to assess a user's mental workload. Determining a user's mental workload is often mentioned as a fundamental problem in IS research (e.g. [4, 5]) from various theoretical perspectives (e.g., cognitive load, task technology fit, job demands-resources), particularly in NeuroIS, e.g. [6-11].
In recent years very interesting results have emerged from NeuroIS in which efforts have been made to determine a user's mental workload based on objective psychophysiological measurements [9-11]. IS scholars have already used pupillary based mental workload assessment using realistic experimental setups, e.g., route planning [12, 13], E-mail classification [12], decision support systems [14], and social networks [7, 15].
To the best of my knowledge there is no study that investigates the relationship between visual website complexity and a user's mental workload using psychophysio-

logical measures – with one exception: The work of Wang et al. [2] investigated website complexity from a cognitive load perspective via eye-tracking technology. Using fixation count and fixation duration they found increased fixation counts, fixation durations and task completion times when performing simple tasks. Interestingly they did not analyze pupillary measures in order to evaluate mental workload.
For this reason I study the usage of three website variants with systematic manipulations of navigation and information complexity using eye-tracking based pupillary diameter responses. This work contributes to IS complexity research, and, in addition, it addresses a very practical problem for website designers.

2 Methodology

2.1 Applying the NeuroIS guidelines

In order to clearly contribute to NeuroIS research and show strong methodological rigor, I strictly followed the NeuroIS guidelines established by vom Brocke et al. [16]. In particular, to assess prior research in the field of measuring mental workload as an important IS construct, a comprehensive literature review was conducted (cf. [17]). To base the experimental design adequately on solid research in related fields of neuroscience [16] I reviewed the fundamental anatomic mechanism of the pupillary dilation controlled by the vegetative nervous system and the key role of the Edinger-Westphal nucleus that is inhibited by mental workload and directly leads to a pupillary dilation. The methodology uses eye-tracking-based pupillometry as a well-established approach in physiology and psychology “widening the 'window' of data collection" [18, p. 93]. With this method, bio-data (i.e. pupil diameter) can be used to better understand mental workload as an IS construct (cf. guideline 4 of [16]). In comparison to other neuroscience tools eye-tracking-based pupillometry is the contact-free and efficient method of choice [19]. I applied the guidelines and standards from Duchowski [20] and the Eyegaze Edge^{TM} manual.

2.2 Measurements

To capture the pupillary diameter, eye-tracking was performed using the binocular double Eyegaze Edge^{TM} System eye-tracker paired with a 19" LCD monitor (86 dpi) set at a resolution of 1280x1024, whereby the eye-tracker samples the pupillary diameter at a rate of 60 Hz for each eye separately.

2.3 Stimuli

Following [21] I manipulated website visual complexity via the number of links in the menu structure (resp. submenus). According to Wang et al. [2] I choose three contrary but balanced levels for navigation and information complexity. Navigation complexity was manipulated by the (sub)menu structure (low: 3 menus; average: 3×3 (sub)menus; high: $3 \times 3 \times 3$ (sub)menus). Information complexity was manipulated by content/text partitioning. All three variants (system A,B,C; see Figure 1) contained the same content/information in summary, but I divided this content into (sub)menu-specific pieces of information. Luminescence levels of the three systems variants were checked (perceived relative luminescence L_A=0.5156, L_B=0.5157, L_C=0.5209).

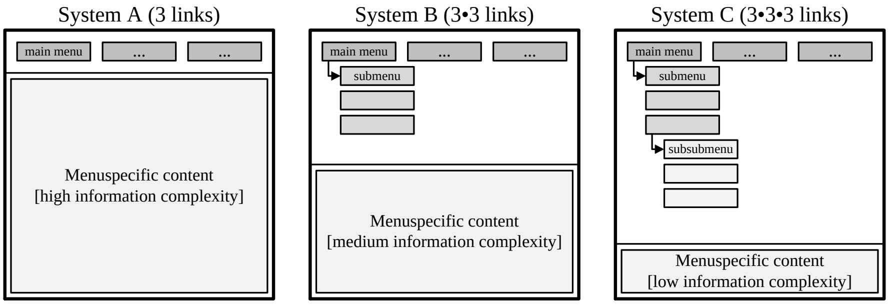

Fig. 1. Conceptualized website complexity (System A: low menu complexity – high information complexity; System B: average menu complexity – average information complexity; System C: high menu complexity – low information complexity)

Please note that I directly tested objective website complexity, since perceived website complexity correlated only medially with objective website complexity (r = 0.3 according to [22, p. 515]).

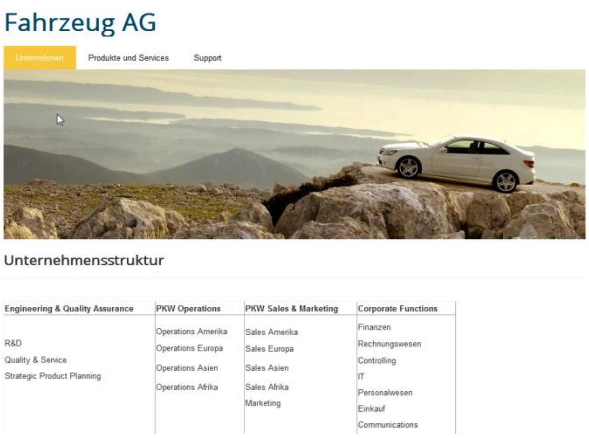

Fig. 2. Exemplary screenshot of system A.

2.4 Description of the test procedure and data cleansing

The participants in the experiment had to perform nine distinctive search tasks – three for each system. In order to counter-balance the design, the test order of the systems (A, B, C) was randomized. In addition, for every test system (A, B, C) three of the nine search tasks were randomly assigned.

Prior to all data collection, each test participant is welcomed by the experimenter (supervisor of the experiment). After that the participant has to fill out a consent form

and also a questionnaire with demographics (stage 1). In stage 2, I take the necessary precautions for the experiment, for which I make use of the eye-tracker. Hence, the eye-tracker is calibrated. In stage 3, the experiment starts with the first of three search tasks the participant has to accomplish. At the end of every tested system (A, B, C), perceived task demands and effort were captured via a NASA TLX questionnaire.
Only naturally determined artifacts, e.g., by eye-blinks, were deleted.

3 Results

3.1 Sample Characteristics

The 45 participants were aged from 22 to 45 years (M=28.6, S.D.=4.7). 24 persons were female, 21 male.

3.2 Relationship between complexity and a user's mental workload

I found clear pupil diameter differences between the three system variants (table 1) which were all significant at small to medium effect sizes (table 2).

Table 1: Mean of pupillary diameters in relation to system variant

System	PD [mm]	
	left eye	**right eye**
System A	3.402	3.451
System B	3.384	3.435
System C	3.428	3.479

Table 2: 2-sided significance test (p-value, t-statistics), effect sizes of different system variants

Comparison	Significance test results	
	left eye	**right eye**
System A vs. system B	$p<0.1$, $t=1.96$, $d=0.29$ (small)	$p<0.1$, $t=1.79$, $d=0.27$ (small)
System A vs. system C	$p<0.05$, $t=2.49$, $d=0.37$ (small)	$p<0.05$, $t=2.63$, $d=0.39$ (small)
System B vs. system C	$p<10^{-5}$, $t=5.05$, $d=0.75$ (medium)	$p<10^{-4}$, $t=4.79$, $d=0.71$ (medium)

4 Discussion, limitations and future research

From a mental workload perspective, the system B is the model of choice since the pupillary based mental workload indicator is lowest for this system variant (small to medium Cohen's d effect sizes). That means for the practical website design perspective that complex menu structures with a lot of menu links and submenus or a design without any submenus should be avoided. Instead, designers should use a balanced combination of submenus (navigation complexity) and text (more information complexity).

From a theoretical point of view this work contributes to IS complexity research. The results indicate that pure navigation complexity (i.e., the number of (sub)menus) or pure information complexity (text) is problematic from a mental workload perspective.

This work has some limitations. The right pupil diameters were slightly larger than for left eyes due to small differences in illumination from the ceiling lights. However, these lighting conditions were kept constant for all participants. In addition, despite designing the experiment as a search task, it cannot be excluded that some participants merely browsed the website. Because there is a mental workload difference between browsing and searching [23], the generalizations of the findings are limited. Furthermore, despite controlling the brightness between the three system variants through the most balanced use of darker text against brighter text background, the variant C is one percent brighter than A and B. However this higher brightness naturally leads to smaller pupils, but not to the larger pupils I found in the experiment. This further strengthens the mental workload effect in system variant C.

In an extended version of this paper I will report on triangulated NASA TLX evaluations, differences in mouse clicks and mouse scrolls as well as results from electrodermal activity assessments. Future work should combine pupillary-based mental workload assessment with novel heat-mapping techniques [24, 25].

Acknowledgements

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References

1. R. Buettner, Investigation of the Relationship Between Visual Website Complexity and Users' Mental Workload: A NeuroIS Perspective. In Information Systems and Neuro Science, vol. 10 of LNISO, pp. 123-128. Gmunden, Austria (2015)
2. Q. Wang, S. Yang, M. Liu, Z. Cao, and Q. Ma, An eye-tracking study of website complexity from cognitive load perspective, DSS, vol. 62, pp. 1-10 (2014)
3. M.-H. Huang, Designing website attributes to induce experiential encounters, Comput Hum Behav, vol. 19, no. 4, pp. 425-442 (2003)
4. H. G. Stassen, G. Johannsen, and N. Moray, Internal representation, internal model, human performance model and mental workload, Automatica, vol. 26, no. 4, pp. 811-820 (1990)
5. G. Johannsen, A. H. Levis, and H. G. Stassen, Theoretical Problems in Man-machine Systems and Their Experimental Validation, Automatica, vol. 30, no. 2, pp. 217-231 (1992)
6. R. Buettner, Analyzing Mental Workload States on the Basis of the Pupillary Hippus, in NeuroIS '14 Proc., 2014, p. 52.
7. R. Buettner, S. Sauer, C. Maier, and A. Eckhardt, Towards ex ante Prediction of User Performance: A novel NeuroIS Methodology based on Real-Time Measurement of Mental Effort, in HICSS-48 Proc., 2015, pp. 533-542.

8. A. O. de Guinea, R. Titah, and P.-M. Léger, Explicit and Implicit Antecedents of Users' Behavioral Beliefs in Information Systems: A Neuropsychological Investigation, JMIS, vol. 30, no. 4, pp. 179-210 (2014)
9. A. Dimoka, P. A. Pavlou, and F. D. Davis, NeuroIS: The Potential of Cognitive Neuroscience for Information Systems Research, ISR, vol. 22, no. 4, pp. 687-702 (2011)
10. A. Dimoka, R. D. Banker, I. Benbasat, F. D. Davis, A. R. Dennis, D. Gefen, A. Gupta, A. Ischebeck, P. H. Kenning, P. A. Pavlou, G. Müller-Putz, R. Riedl, J. vom Brocke, and B. Weber, On the Use of Neurophysiological Tools in IS Research: Developing a Research Agenda for NeuroIS, MISQ, vol. 36, no. 3, pp. 679-A19 (2012)
11. R. Riedl, R. D. Banker, I. Benbasat, F. D. Davis, A. R. Dennis, A. Dimoka, D. Gefen, A. Gupta, A. Ischebeck, P. Kenning, G. Müller-Putz, P. A. Pavlou, D. W. Straub, J. vom Brocke, and B. Weber, On the Foundations of NeuroIS: Reflections on the Gmunden Retreat 2009, CAIS, vol. 27, pp. 243-264 (2010)
12. S. T. Iqbal, P. D. Adamczyk, X. S. Zheng, and B. P. Bailey, Towards an Index of Opportunity: Understanding Changes in Mental Workload during Task Execution, CHI '05 Proc., pp. 311-320 (2005)
13. B. P. Bailey and S. T. Iqbal, Understanding Changes in Mental Workload during Execution of Goal-Directed Tasks and Its Application for Interruption Management, ACM TOCHI, vol. 14, no. 4, Article 21, pp. 1-28 (2008)
14. R. Buettner, Cognitive Workload of Humans Using Artificial Intelligence Systems: Towards Objective Measurement Applying Eye-Tracking Technology, in KI 2013 Proc., ser. LNAI, vol. 8077, 2013, pp. 37-48.
15. R. Buettner, B. Daxenberger, A. Eckhardt, and C. Maier, Cognitive Workload Induced by Information Systems: Introducing an Objective Way of Measuring based on Pupillary Diameter Responses, in Pre-ICIS HCI/MIS 2013 Proc., 2013, paper 20 (2013)
16. J. vom Brocke and T.-P. Liang, Guidelines for Neuroscience Studies in Information Systems Research, JMIS, vol. 30, no. 4, pp. 211-234 (2014)
17. J. vom Brocke, A. Simons, B. Niehaves, K. Riemer, R. Plattfaut, and A. Cleven, Reconstructing the Giant: On the Importance of Rigour in Documenting the Literature Search Process, in ECIS '09 Proc., pp. 2206-2217 (2009)
18. S. D. Goldinger and M. H. Papesh, Pupil Dilation Reflects the Creation and Retrieval of Memories, Curr Dir Psychol Sci, vol. 21, no. 2, pp. 90-95 (2012)
19. B. Laeng, S. Sirois, and G. Gredebäck, Pupillometry: A Window to the Preconscious? Perspect Psychol Sci, vol. 7, no. 1, pp. 18-27 (2012)
20. A. T. Duchowski, Eye Tracking Methodology: Theory and Practice, 2nd ed. London, UK: Springer (2007)
21. L. Deng and M. S. Poole, Affect in Web Interfaces: A Study of the Impacts of Web Page Visual Complexity and Order, MISQ, vol. 34, no. 4, pp. 711-A10 (2010)
22. S. Nadkarni and R. Gupta, A Task-Based Model of Perceived Website Complexity, MISQ, vol. 31, no. 3, pp. 501-524 (2007)
23. W. Hong, J. Y. Thong and K. Y. Tam, The effects of information format and shopping task on consumers' online shopping behavior: A cognitive fit perspective. JMIS, vol. 21, no. 3, pp. 149-184 (2004)
24. A. Eckhardt, C. Maier, J. J. Hsieh, T. Chuk, A. B. Chan, J. H. Hsiao and R. Buettner, Objective measures of IS usage behavior under conditions of experience and pressure using eye fixation data. In ICIS 2013 Proc. (2013).
25. V. Georges, F. Courtemanche, S. Sénécal, T. Baccino, P.-M. Léger and M. Frédette, Measuring Visual Complexity Using Neurophysiological Data. In Information Systems and Neuro Science, vol. 10 of LNISO, pp. 207-212. Gmunden, Austria (2015)

Studying the Creation of Design Artifacts

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Abstract. As software and information systems (IS) increase in functional sophistication, perceptions of IS quality are changing. Moving beyond issues of performance efficiency, essential qualities such as fitness for purpose, sustainability, and overall effectiveness become more complex. Creating software and information systems represents a highly interconnected locus in which both the generative processes of building design artifacts and articulating constructs used to evaluate their quality take place. We address this interconnectedness with an extended process-oriented research design enabling multi-modal neurophysiological data analyses. We posit that our research will provide more comprehensive assessments of the efficacy of design processes and the evaluation of the qualities of the resulting design artifacts.

Keywords: IS Design · Creating Design Artifacts · Personal Construct Psychology (PCT) · Event-related potential (ERP) · Eye-tracking · Eye fixation related potential (EFRP) · Electroencephalography (EEG) · Interaction Logging · Repertory Grid Analysis (RGA)

1 Introduction

Creative design activities are central to all applied engineering disciplines. The information systems (IS) field since its advent has the principal objective of designing, building, and evaluating systems to solve complex business problems. IS as composed of inherently mutable and adaptable hardware, software, telecommunications, and human interfaces provide many unique and challenging design problems that call for new, creative ideas and discovery. IS artifacts are implemented within an application context for the purpose of improving the effectiveness and efficiency of that context. The utility of the artifact and the characteristics of the application – its work systems, its people, and its development and implementation methodologies – together determine the extent to which that purpose is achieved. Researchers produce new ideas that enhance generative capacity

[1] and improve the ability of human organizations to adapt and succeed in the presence of changing environments. These generative ideas are then communicated as knowledge to the various IS communities [2].

The IS design environment is characterized by significant (and increasingly complex) generative opportunities presented by the diversification of rapidly evolving technologies in terms of development focus and medium (e.g. 'wrappers' for legacy systems; XaaS; cloud/virtualization; mobile apps) and agility (e.g. speed of creation and deployment). Creative design activities are supported by a plethora of representational methods and tools. With all of this richness of creative design opportunities and enabling creative infrastructures, IS researchers still struggle to understand the process of creating artifacts in IS design - and how to measure their quality. Thus, we pose the research question: Has the diversification of functionalities, development environments, tools (e.g. representational languages) etc. expanded the range of criteria that are used to guide the creative design process and improved our ability to judge the quality of design artifacts? In other words, have new understandings and theories of creating design artifacts emerged in response to advances in design processes and tool evolution and their innovative use? We posit that the answer is *Yes*. The remainder of this paper presents a comprehensive research design and protocols that enable emergent characteristics of design quality to be identified and articulated, providing insight into the process of creating design artifacts. We triangulate a rich array of previously inchoate empirical data sources to rigorously address the research question set out above. This paper extends research proposed by Davis and Hevner [3] on how designers employ visual syntax in the process of creating IS design artifacts.

2 The Creation of Design Artifacts

Design is both a process and a product. It describes the world as acted upon (processes) and the world as sensed (artifacts). In this research the phenomena of interest are the creation process and the quality assessment of the created design artifacts. As we have noted previously [4] this view of design supports a problem-solving paradigm that continuously shifts perspective between design processes and designed artifacts for the same complex problem. The design process is a sequence of activities tapping a range of expertise that produces an innovative product (i.e., the design artifact). The perceived qualities of the artifact enable evaluation which provides feedback, leading to a better understanding of the design challenge and, in turn, to improvement of the qualities of both the product and the design process.

Hevner, Davis, Collins, and Gill [4] propose a 2x2 model of the design process from the perspective of neuroscience. The x-axis distinguishes the External (Task) Environment from the Internal (Cognitive) Environment; the y-axis separates the Problem Space from the Solution Space. In this research, we focus on the iterations of observation and generation of candidate designs that advance the design process from the upper-right internal problem space to the lower-right internal solution space, creating new, effective candidate solutions in response to the requirements in the problem space – the process of creation. This flow enables creative design events – decisions and actions – to be captured and analyzed in real-time. The form and immediacy of the post-task analyses articulate the constructs that guide design events and evaluation of the quality of the candidate solution artifact. Our research framework overcomes the limitations of instruments such as the Remote Associates Test and the Alternative Uses Task: their emphasis on comprehension limits their capacity to accommodate emerging, i.e. not yet fully known, cognitive constructs.

The specific questions addressed here concern the characteristics used to guide the creation of conceptual models (e.g. UML diagrams). We argue that this generative component of design differs substantially from the primarily comprehension based tasks that have guided prior research (e.g. [5-8]). Our goal is to identify the constructs used by designers to articulate the qualities that guide creating and evaluating designs. Our prior work [9] shows that the combination of neurophysiological data – particularly those elicited using the EFRP and ERP protocols – and interaction logs provide an authoritative basis to identify design decisions and the quality characteristics driving them. In this paper, we present a comprehensive research design and protocol, in Sections 3 and 4, respectively, that enable neurophysiological data and interaction logs to be synchronized. This composite data set provides the basis for eliciting the constructs undergirding design choices and design actions, i.e., interactions with the design platform.

3 Research Design

The build and evaluate cycles of design are typically iterated a number of times before the final (use) artifact is released into an application context for further testing and assessment through field study. During the process of creating and refining design artifacts the researcher must be cognizant that both the design process and the design artifact evolve as the research progresses. Kelly's [10] Personal Construct Theory (PCT) accommodates the socio-cognitive milieu that characterizes the co-evolution of the process of creating design artifacts and the constructs that guide their evaluation.

PCT [10] was developed as a framework for understanding how people made sense of the world around them. Kelly argued that people act as 'lay epistemologists' [11] in their attempts to order and interpret their experiences, categorizing and discriminating between them. In this way, individuals develop systems of interrelated personal constructs that enable them to anticipate the consequences of their own actions – and interpret the actions of others. PCT allows researchers to tap into the mental models used by individual designers to frame and articulate the world as acted upon and the world as sensed. PCT is particularly well suited to our phenomenon of interest – the qualities guiding the process of creating and evaluating design artifacts.

PCT is translated into practice using a cognitive mapping technique called Repertory Grid Analysis (RGA). Individuals' perceptions of similarity and difference are elicited, tapping into their theories of how the world operates. Use in its 'minimum context' form exploits the potential of RGA to directly tap designers' perceptions. This maintains the integrity of "the complex interconnectedness of the self and its social surroundings" [12, p345] providing two substantial benefits. First, it accommodates a wide range of empirical data types during elicitation of perceptions of the design process and product, including intermediate versions of the design artifact in the processes of building artifacts and evaluating progress. This enables design decisions that drive evolution of the design artifact from one version to another to be articulated directly by their creator. Second, relying on PCT to guide analysis of these constructs provides more ready and authentic construing of construction processes by members of the design community that we study. This responds directly to calls from the NeuroIS community for robustness and rigor in the application of neuro techniques [13]. The need for a more a comprehensive research protocol in order to accommodate the longer-term (multi-episodic) series of cognitive 'events' that generative tasks associated with creating software design artifacts entail is highlighted by Weber et al. [9]. The protocol set out below strives to maintain the 'interconnectedness' of designer and design [12] in a workplace setting, significantly increasing the immersion of the research into the design context - and authenticity of the analyses.

4 Research Protocol

Figure 1 outlines the research protocol and shows a three-phase 'immersion' into the complex interconnectedness of design environments. In order to exploit the capacities of PCT and RGA, identification of cognitive 'events' indicating design decisions and reconstruction of the design artifact before and after the design decision are required. In Phase 1 the designer works on a design task, i.e., creates a design artifact using a design platform. During this phase we rely on multi-modal data collection: we conduct neuro-physiological measurements, collect EEG data and instrument the design platform to simultaneously gather data on the design activities, i.e., interactions with the design platform. Data are synchronized using timestamps.

In Phase 2 we address the transition of designers from creating to evaluating: the events that interconnect designer and design. The stream of neurophysiological data is used to identify relevant cognitive events, i.e., the points in time when decisions took place, using the ERP and EFRP protocols with the EEG data. Timestamps are used to extract an intermediate model associated with each cognitive event from the stream of design activities [14-17] providing a secure basis for data triangulation.

In Phase 3 a series of steps is used to elicit personal constructs. Firstly, intermediate model versions are presented to the designer three at a time: their similarities and differences are used to articulate the 'poles' of a dimension that differentiate them. The poles provide the labels for a row in the repertory grid. This step is repeated until all version combinations have been exhausted and/or repetition occurs. The columns of the grid are labelled using the (numbered) model versions – the design task 'elements' that the grid represents. The rows are also numbered, 1 indicating the left-side label and 5 indicating the right-side label, providing a simple Likert scale for later use.

The (subject) designer completes the next step alone: working one row at a time, the designer rates each model version (element) using the 1-5 scale. The completed grid is analyzed using two-dimensional (spaced-focused) cluster analysis to re-order the grid and add dendograms (crow's feet) to illustrate the linkages or clustering of the constructs.

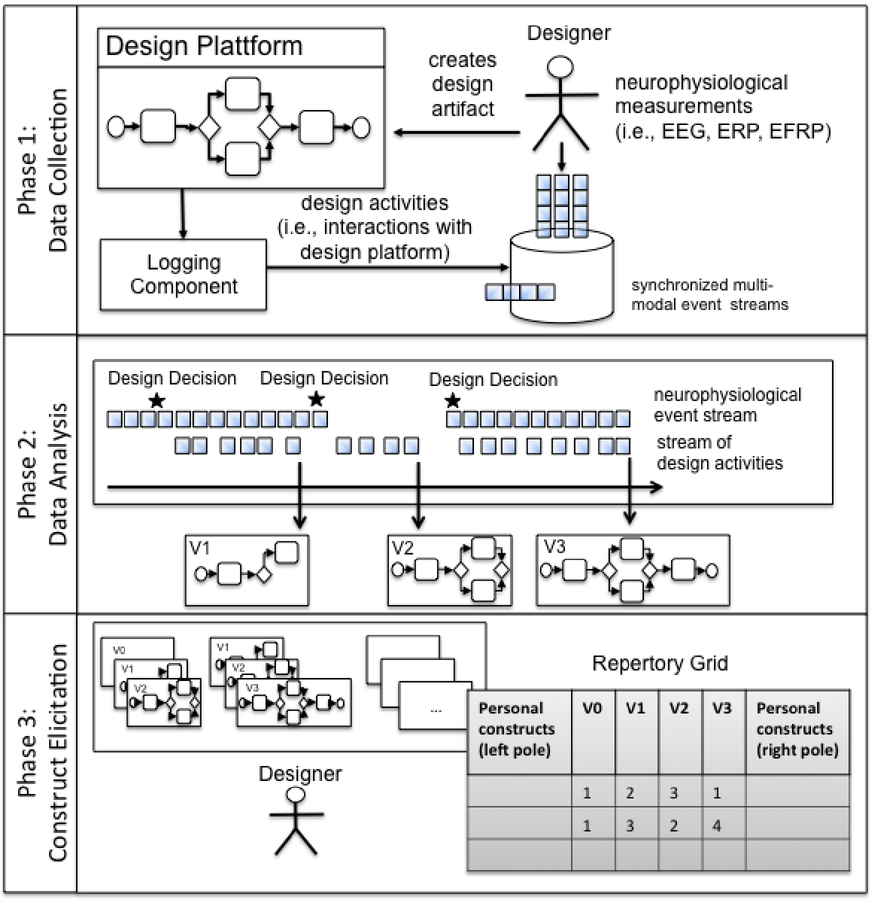

Figure 1 Immersive Analysis Protocol

The final step uses a protocol called 'talkback' to guide reflection on the spaced-focused grid. The designer articulates the qualities that characterize the most closely linked constructs: these are recorded by the researcher. This interview phase is iterative, moving from the smallest clusters 'outwards' to articulate more universal constructs. The system of inter-related constructs that represent the subject designer's view of the essential characteristics of design is captured in this phase.

The protocol balances the subject-centricity offered by PCT – essential to elicit the constructs guiding the process of creating and evaluating design artifacts – with the rigor of the detection of intermediate versions of the design artifact from interaction logs, ERP, EFRP and RGA protocols. There are three specific benefits: (i) accommodation of a range of complementary data types; (ii) maintenance of data cohesion and 'interconnectedness' by eliciting and analyzing them in a well-bounded experimental setting (i.e. generative design in the world of the designer); and (iii) exploiting the capacity of minimum context RGA and the talkback protocol to provide a medium – or ‘conversational technology’ [18] – that enables expert subjects *themselves* to interpolate the disparate data types generated during the experiment. This adds coherence and accommodates the longevity and cumulative nature of design, enabling investigation of design decisions and model interactions in near to real-time. Further, the RGA protocols mitigate limitations of techniques such as talk-aloud, removing the risks associated with loss of recall and interference with neurophysiological data gathering. The re-connection of designer and design process through RGA overcomes these limitations, enabling disparate data types to be orchestrated in real-time to provide new insights into the design process as it unfolds in the work setting

We anticipate that prompt use of RGA to re-immerse the subject in their design experience will enable the constructs used to create and evaluate design artifacts to be readily and reliably elicited. Prior use of these protocols has been revelatory to both researcher and subjects, identifying constructs that had previously neither been anticipated or articulated [11]. Such emergent constructs will, we envisage, enable the range of criteria used to assess the utility and other qualities of design processes and artifacts to be significantly expanded.

5 Discussion and Future Directions

The research design is novel: the phenomena of interest – the design processes and the qualities of the artifacts they generate – have proved elusive. This novelty is complemented by focus on the creative transitions between building and evaluating, offering new insight into the qualities that drive the processes of creating and selecting candidate design artifacts.

The combination of process-orientation with multi-modal data gathering has significant benefits and implications for both theory and practice. The immersive analysis substantially extends and enriches assessment of design processes and artifacts. Fuller understanding of the qualities that guide design decisions during the creation of design artifacts will also provide useful advice for practicing designers and trainers.

PCT maintains the interconnectedness of designer and design and moves towards a more tractable definition of creation - the ‘process of creating design artifacts’, overcoming the limitations of prior neuro and NeuroIS studies [13, 14]. For instance, research into conceptual modeling is dominated by comprehension-oriented tasks (e.g., [19-22]) rather than conceptual modeling tasks (e.g., [23]) and research settings applying neuro-physiological tools favor static diagrams over (dynamic) processes (e.g., [5-8]). Moreover, in a more general context, most of the studies applying neurophysiological tools in IS are stimulus-response tasks rather than generative - addressing short-term experiments (episodes) rather than longer-term processes [14, p. 107].

The paper also serves as an invitation to the NeuroIS community to provide feedback on the feasibility and viability of the research design and to explore collaborative means of achieving the critical mass of resources required to bring it to fruition.

References

1. Avital, M. and Te'eni, D. (2009) From generative fit to generative capacity: Exploring an emerging dimension of information systems design and task performance. *Information Systems Journal, 19(4)*, 345-367.
2. Gregor, S. and Hevner, A. (2013) Positioning and presenting design science research for maximum impact, *Management Information Systems Quarterly, 37(2)*.
3. Davis, C. and Hevner, A. (2015) Neurophysiological Analysis of Visual Syntax in Design. *Information Systems and Neuroscience: Gmunden Retreat on NeuroIS*, Springer, Gmunden, Austria, pp. 99-106.
4. Hevner, A., Davis, C., Collins, R. and Gill, T. (2014) A NeuroDesign Model for IS Research. *Informing Science: The International Journal of an Emerging Transdiscipline* 17, pp. 103–132.
5. Mendling, J., Strembeck, M., Recker, J. (2012) Factors of process model comprehension — findings from a series of experiments. *Decision Support Systems* 53(1), 195–206.
6. Figl, K., Recker, J., Mendling, J. (2013) A study on the effects of routing symbol design on process model comprehension. *Decision Support Systems* 54(2), 1104–1118.
7. Figl, K., Mendling, J., Strembeck, M. (2013) The influence of notational deficiencies on process model comprehension. *Journal of the Association for Information Systems*, 14(6), Article 1
8. Recker, J., Reijers, H.A., Van de Wouw, S.G. (2014) Process model comprehension: the effects of cognitive abilities, learning style, and strategy. *Communications of the Association for Information Systems* 34(9), 199–222.
9. Weber, B., Pinggera, J., Neurater, M., Zugal, S., Martini, M., Furtner, M., Sachse, P. and Schnitzer, D. (2016) Fixation Patterns During Process Model Creation: Initial Steps Toward Neuro-adaptive Process Modeling Environments *Proceedings of the 49th Hawai'i International Conference on Systems Sciences* (HICSS49) Kauai, Hawai'i, pp. 600-609.
10. Kelly, G. (1955) The Psychology of Personal Constructs. Norton, London, UK
11. Davis, C. and Hufnagel, E. (2007) Through the Eyes of Experts: A Socio-cognitive Perspective on the Automation of Fingerprint Work. *MIS Quarterly* 31(4), pp. 681-703.
12. Neimeyer, G. and Neimeyer, R. (1985) Relational Trajectories: A Personal Construct Contribution. Journal of Social and Personal Relationships 2, pp. 325-349.
13. Riedl, R., Davis, F. and Hevner, A. (2014) Towards a NeuroIS Research Methodology: Intensifying the Discussion on Methods, Tools and Measurement. *Journal of the Association for Information Systems* 15, pp. i–xxxv.
14. Riedl, R., Léger, J-P., Fundamentals of NeuroIS (2016). Information Systems and the Brain. Studies in Neuroscience, Psychology, and Behavioral Economics. Berlin, Heidelberg, Springer.
15. Müller-Putz, G., Riedl, R. and Wriessnegger, S. (2015) Electroencephalography (EEG) as a Research Tool in the Information Systems Discipline: Foundations, Measurement and Applications. Communications of the Association of Information Systems 37(46) pp 911-948.
16. Pinggera, J., Zugal, S., Weidlich, M., Fahland, D., Weber, B., Mendling, J. and Reijers, H. (2012). Tracing the Process of Process Modeling with Modeling Phase Diagrams. In: Proc. ER-BPM '11, pp. 370–382.
17. Pinggera, J., Zugal, S. and Weber, B. (2010). Investigating the Process of Process Modeling with Cheetah Experimental Platform. In: Proc. ER-POIS '10, pp. 13–18.
18. Thomas, L. and Harri-Augstein, S. (1985) Self-Organized Learning: Foundations of a Conversational Science for Psychology. Routledge & Kegan-Paul, plc London, UK.

19. Matsuo, N., Ohkita, Y., Tomita, Y., Honda, S. and Matsunaga, K. (2001) Estimation of an Unexpected-Overlooking Error by Means of the Single Eye Fixation Related Potential Analysis with Wavelet Transform Filter. *International Journal of Psychophysiology* 40(3), pp. 195-200.
20. Takeda, Y., Sugai, M. and Yagi, A. (2001) Eye Fixation Potentials in a Proof-reading Task. *International Journal of Psychophysiology* 40(3), pp. 181-186.
21. vom Brocke, J., Riedl, R. and Léger, P. (2013) Application Strategies for Neuroscience in Information Systems Design Science Research. *Journal of Computer Information Systems* 53(3), pp. 1–13.
22. Recker, J., Safrudin, N., Rosemann, M. (2012) How novices design business processes. Inf. Syst. 37 (6), 557–573.
23. Hungerford, B., Hevner, A., and Collins, R. (2004) Reviewing Software Diagrams: A Cognitive Study. *IEEE Transactions on Software Engineering* 30(2), pp. 82-96.

Bridging Aesthetics and Positivism in IS Visual Systems Design with Neuroscience: A Pluralistic Research Framework and Typology

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Abstract: In this paper, we proposed a neuroscience-based general framework for IS visual systems design that uses neuroscience as the bridge that systematically integrates the principles of design aesthetics and principles of positivistic functionalities into a comprehensive model. Based on our general conceptual model, we also provide a detailed typological framework for the practical IS visual systems design.

Keywords: Neuroscience, NeuroIS, aesthetics, positivism, systems design, methodology, topological framework

1. Introduction

Information systems (IS) visual system design is an important component of the general concept of information design. As [1] point out, "in order to satisfy the information needs of the intended receivers, information design comprises analysis, planning, presentation and understanding of a message – its content, language and form… a well-designed information set, with its message, will satisfy aesthetic, economic, ergonomic, as well as subject matter requirements" (p.19). In the past decades, visual system design has become an increasingly relevant topic in IS, as evidenced by a plethora of relevant studies [2-6]. Generally, in IS there are two research streams that address visual system design [7]: one holds that interface usability and functionality is the key, emphasizing a behavioral or cognitive focus [8-12]; the other research stream contends that attention to hedonic aspects of human-computer interaction, with human needs such as emotion, affect, and experience is important [13-15].

Traditionally in the IS field, the visual system design is studied through the positivist paradigm with a functional approach. According to this approach, the IS system design methodology focuses on the user's cognitive perceptions of the IS visual system design artifacts, and the factors influencing such perceptions. The research papers with this approach usually utilize the terms "design," "development," "dimension," "construct," "characteristic," "variable," and "factor". There are three positivist dimensions that form the premises of IT systems development [16]: factors of systems development, user outcomes, and owner value outcomes [17, 18].

Historically, there exists another separated paradigm for visual system design: the aesthetics of information design that focuses on the visual impression that "is both instantaneous and persistent in memory" [19]. The vocabulary used by researchers with this approach usually includes terms such as "visual," "aesthetic," "sensory," "interactive," and "beauty". The three aesthetic dimensions that form the fundamental premises of the visual design discipline and well-established in the literature are: elements of visual design, principles of visual design, and factors of visual composition [20-24].

Researchers have argued for a systematic approach that can integrate these two distinct, and currently mostly-independent paradigms, and call for a comprehensive framework that illustrates the IS visual systems design with both functionality and aesthetic appeals [25, 26]. In this paper, we propose an innovative framework to integrate these two disparate paradigms: we use neuroscience as an underlying connection bridging aesthetics design principles with positivistic design principles. On one hand, we illustrate the design model for Neuro-aesthetics, and on the other hand, we also describe the NeuroIS model for system design. Then we show that these two approaches can be seamlessly integrated into one comprehensive framework for IS visual systems design. In addition, based on our proposed general framework, we develop a typological model for the practical application of visual systems design.

2. Neural Foundation for IS Design Science

In IS field, design science research refers to the stream of research that focuses on the "development of novel IT artifacts, organizational development, and theory building" [27, 28]. Traditionally this area has provided structure and direction to the design of IS components, and identified factors that influence the processes [29].

One field that holds great promise in contributing to the above area of IS design science is neuroscience, which is the science that explains how human brain works. NeuroIS is the emerging field that focuses on the integration of neuroscience and IS [30, 31]. And especially in IS design science, for which human cognitive perceptions and decision making play a critical role, neuroscience provides great potential in contributing to the enhancement of IS design science methodology. The intersection between NeuroIS and IS design science has been investigated extensively since 2010 [32-35].

In this paper, we adopt [29]'s NeuroIS Design Science Model to illustrate the neural foundation for IS design science. Their model focuses primarily on three steps of interaction between human designers' neural activities and IS artifacts, and can briefly described as following:

- In the first step, the designers measure the artifact efficiency using neuroscience and generate neurophysiologic data. The step can be closely mapped to the dimension of "factors of systems development" in the positivist premise of IT systems development.
- In the second step, new or improved IS artifacts and interfaces are designed, developed and built using the measurement data generated from the first step, in order to enhance

the efficiency of the system. The system efficiency can be measured through neurophysiologic values such as cognitive load, stress, and working memory, etc. This step can be closely mapped to the dimension of “user outcomes” in the positivist premise of IT systems development.

- Finally, the outcomes of the new or improved IS artifacts are tested and evaluated using neural cognitive methods to provide an overall evaluation to the system owners. This step can be closely mapped to the dimension of “owner value outcomes” in the positivist premise of IT systems development.

Therefore, the neural foundation for IS design science can thus be modeled by the following figure 1:

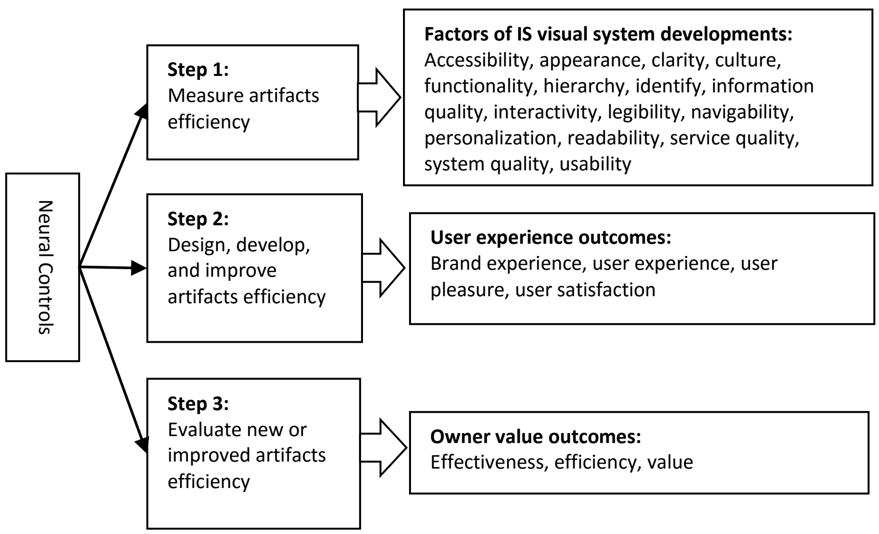

Figure 1. The model of neural foundation for IS system design science

3. Neural Foundation for Aesthetic Perception

As [36] pointed out, there are parallels between properties of art, more specifically, the principles of perception, and organizational principles of the brain. Production and perception of art ought to conform to principles of neural organizations. Neuro-aesthetics is an emerging area, and various researchers have proposed models of visual aesthetic appreciation, perception, and judgments based on cognitive neuroscience. Two main neuroaesthetic models are [37] and [38].

In [37]’s model, the neural processes for aesthetic interaction starts with an affective state invoked by a design artifact, and goes through steps of perceptual analysis, implicit memory integration, explicit classification, cognitive mastering, and evaluation, before it reach the stage of aesthetic judgment and aesthetic emotion. During each of the steps, the outcomes of those steps are significantly influenced by various factors such as complexity, contrast, order, grouping, familiarity, style, and contents, among others.

In [38]'s model, the visual artifact offers stimuli, to which the users respond with attention efforts based on early vision features (such as orientation, shape, and color, etc.), and then intermediate vision (by grouping). As a result, the users make a decision influenced by emotional response.

To summarize the neural models for aesthetics, we can categorize the aesthetic characteristics derived from neural visual perception into three broad categories:

- Factors of composition, which includes elements of axis, complexity, dominance, focus, layout, order, sequence, and rules of composition;
- Principles of visual design, which includes balance, contrast, emphasis, gestalt, movement, pattern, proportion, rhythm, and unity;
- Elements of visual design, which includes color, form, line, point, shape, space, texture, typography, and value.

Therefore, the neural foundation for aesthetics can thus be modeled by the following figure 2:

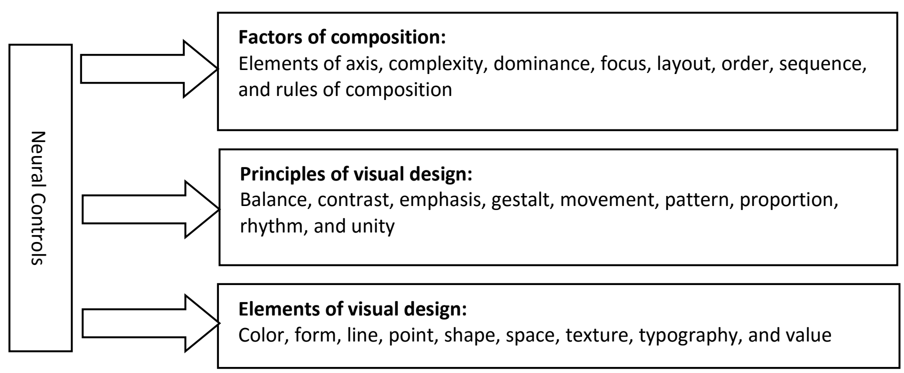

Figure 2. The model of neural foundation for aesthetics

4. A General Framework for Neuro-Scientific IS Visual System Design

Based on the description of the previous analyses, it can be noticed that neural controls play a critical role in bridging the two seemingly disparate paradigms of IS visual system design: aesthetic design principles and positivistic design principles. Another important characteristic of this neuro-scientific integrated visual system design approach is that neural controls function in a behind-the-scene, under-the-hood fashion. Their intricate functionalities and mechanisms in influencing either positivistic IS design decisions or aesthetic design perceptions are critical in understanding how the decisions and perceptions are formed. However, these neural controls' detailed intricacies are encapsulated from the implementation of the design framework in real-world designing scenarios. People do not need to understand the detailed neural functionalities of various controls to appreciate the integration of traditional IS system design methodologies and aesthetics principles.

In the following Figure 3, we show the neural factors as the bridging components in connecting aesthetics visual design dimensions (as identified by Figure 2) and functional system design dimensions (as identified by Figure 1).

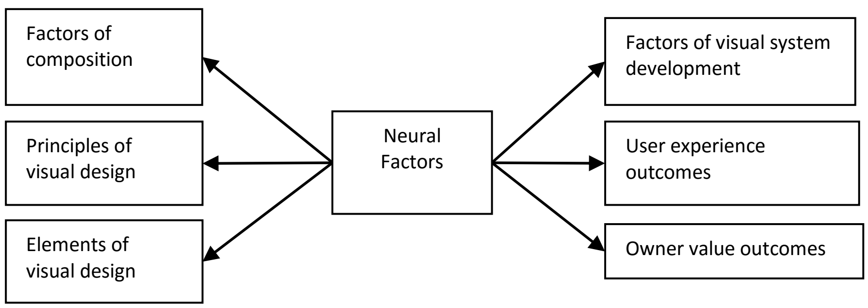

Figure 3. Neural factors as a bridge between aesthetics and functional system design

Next, we encapsulate the neural factors underlying the connections between aesthetic dimensions and functional dimensions, and present the general framework for visual system design as illustrated by the following Figure 4.

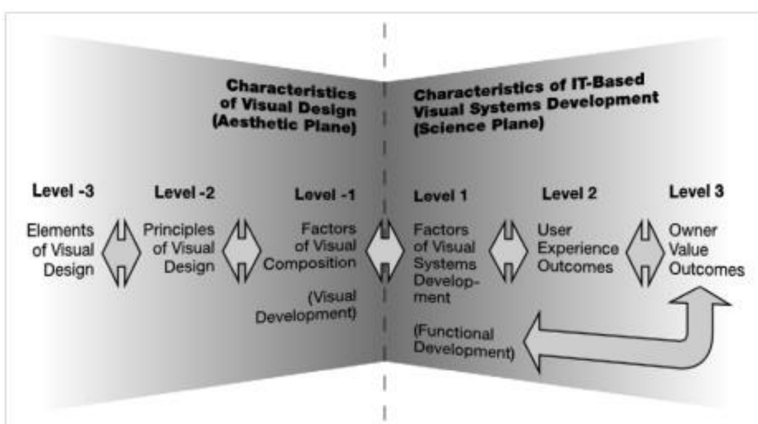

Figure 4. A general framework for neuro-scientific visual systems design

The interactive flows between all dimensions are bi-directional, meaning that the higher-level compositional requirements (Level -1 in Figure 4) potentially dictate the knowledgeable designer's choice of the lower-level principles (Level -2), which in turn may dictate the choice of the lowest level elements (Level -3). IT system developers know that poor functional system design usually results in an inferior system. Analogously, because elementary (-3) design choices can profoundly affect principles (-2) and then exert influence through the compositional factors (-1), a designer who does not understand visual design theory and the possible hierarchical and interactive effects of his/her design choices will likely produce inferior visual designs.

5. A Topological Framework for a Balanced Visual Systems Design

Based on our proposed general conceptual framework for neuro-scientific visual systems design, we are able to establish a typological framework of balanced visual systems design. We start with each dimension in our conceptual frame. We identify each element within the dimension as the building blocks of design, and divide each into additional qualities, or subordinate attributes, as sub-variables. Then we provide a detailed description of each sub-variable, and identify its factor type and class.

The 49 factors or variables listed in our conceptual framework collectively generate over 150 qualities. Due to the length limit of this paper, we are not able to include the whole typological framework in this paper. The following Figure 5 is a snapshot of the portion of the framework pertaining to the element of "color" in the dimension of "elements of visual design" within the aesthetic plane.

Paradigm	Level	Design Factor	Description	Factor Type	Class
Aesthetic			An overarching conceptual model based on theory, study, and practice of beauty	Construct	Paradigm
	-3		The first-order visual dimension of the visual aesthetic paradigmatic plane, containing compositional factors visual aesthetic design--resulting from combination and manipulation of elements and principles. All variables in this dimension are composed of sub-variable "qualities"--characteristics that help define the factors.	Dimension	Characteristic of Visual Design
		Color	The perception of particular wavelengths of light as specific hues by the color receptors of the human eye	Variable	Element of Design
			Qualities: Hue, Saturation, Luminance, Chrominance, Complementary, Associative, Analogous, Surface area occupied	*Sub-Variables*	

Figure 5. A snapshot of the typological framework of visual systems design

6. Conclusion

In this paper, we present a general conceptual framework based on neuroscience that systematically integrates aesthetic principles and traditional positivistic IS design science methodology. In addition, based on our conceptual model, we establish a typological framework that directly provides the practical guidelines of a visual system design approach which balance the aesthetic and functional aspects of system design.

For future research, a couple of possible directions are interesting in extending the research outcome from this paper. First of all, we believe it would be interesting to design an experiment to evaluate the implementation of the typological framework developed in this paper and test how well it performs with an actual IS visual system (e.g. a functional website) design. Another interesting topic would be to obtain more details about how exactly the various neural controls affect the aesthetic perception and positivistic decision making and thus explore deeper insights towards the integrated relationships between these two planes in our proposed framework as illustrated in Figure 4.

References

1. Pettersson, R.: Information design, an introduction. John Benjamins Publishing Company, Amsterdam/Philadelphia (2002)
2. Benbasat, I.: HCI research: Future challenges and directions. AIS Transactions on Human-Computer Interaction 2, 1 (2010)
3. Li, N.L., Zhang, P.: The intellectual development of human-computer interaction research: A critical assessment of the MIS literature (1990-2002). Journal of the Association for information Systems 6, 9 (2005)
4. Prestopnik, N.R.: Theory, design and evaluation–(Don’t just) pick any two. AIS Transactions on Human-Computer Interaction 2, 167-177 (2010)
5. Zhang, P., Benbasat, I., Carey, J., Davis, F., Galletta, D.F., Strong, D.: AMCIS 2002 panels and workshops I: Human-computer interaction research in the MIS discipline. Communications of the Association for Information Systems 9, 20 (2002)
6. Zhang, P., Li, N., Scialdone, M., Carey, J.: The intellectual advancement of human-computer interaction research: A critical assessment of the MIS literature (1990-2008). AIS Transactions on Human-Computer Interaction 1, 55-107 (2009)
7. Cyr, D., Head, M., Larios, H., Pan, B.: Exploring human images in website design: a multi-method approach. MIS quarterly 539-566 (2009)

8. Babu, R., Singh, R., Ganesh, J.: Understanding blind users' Web accessibility and usability problems. AIS Transactions on Human-Computer Interaction 2, 73-94 (2010)
9. Palmer, J.W.: Web site usability, design, and performance metrics. Information systems research 13, 151-167 (2002)
10. Reber, R., Schwarz, N., Winkielman, P.: Processing fluency and aesthetic pleasure: Is beauty in the perceiver's processing experience? Personality and social psychology review 8, 364-382 (2004)
11. Teo, H.-H., Oh, L.-B., Liu, C., Wei, K.-K.: An empirical study of the effects of interactivity on web user attitude. International Journal of Human-Computer Studies 58, 281-305 (2003)
12. Venkatesh, V., Ramesh, V.: Web and wireless site usability: understanding differences and modeling use. MIS quarterly 181-206 (2006)
13. Agarwal, R., Karahanna, E.: Time flies when you're having fun: Cognitive absorption and beliefs about information technology usage. MIS quarterly 665-694 (2000)
14. Beaudry, A., Pinsonneault, A.: The other side of acceptance: studying the direct and indirect effects of emotions on information technology use. MIS quarterly 689-710 (2010)
15. Schrepp, M., Held, T., Laugwitz, B.: The influence of hedonic quality on the attractiveness of user interfaces of business management software. Interacting with Computers 18, 1055-1069 (2006)
16. Iivari, J., Hirschheim, R., Klein, H.K.: A paradigmatic analysis contrasting information systems development approaches and methodologies. Information systems research 9, 164-193 (1998)
17. Valacich, J.S., Parboteeah, D.V., Wells, J.D.: The online consumer's hierarchy of needs. Communications of the ACM 50, 84-90 (2007)
18. Peak, D.A., Gibson, M.R., Prybutok, V.R.: Synergizing positivistic and aesthetic approaches to improve the development of interactive, visual systems design. Information design journal+ document design 19, 103-121 (2011)
19. Lindgaard, G., Fernandes, G., Dudek, C., Brown, J.: Attention web designers: You have 50 milliseconds to make a good first impression! Behaviour & information technology 25, 115-126 (2006)
20. Edwards, D.J.: The Handbook of Art and Design Terms. Pearson, Prentice Hall (2004)
21. Krug, S.: Don't Make Me Think: A Common Sense Approach to the Web (2nd Edition). New Riders Publishing (2005)

22. Mandiberg, M.: Digital foundations: intro to media design with the Adobe Creative Suite. Peachpit Press (2008)
23. Mullet, K., Sano, D.: Designing visual interfaces: Communication oriented techniques. (1994)
24. Rand, P.: Design Form and Chaos. Yale University Press (1993)
25. Peak, D.A., Prybutok, V.R., Gibson, M., Xu, C.: Information systems as a reference discipline for visual design. International Journal of Art, Culture and Design Technologies (IJACDT) 2, 57-71 (2012)
26. Peak, D.A., Prybutok, V.R., Wu, Y., Xu, C.: Integrating the visual design discipline with information systems research and practice. Informing Science: the International Journal of an Emerging Transdiscipline 14, 161-182 (2011)
27. Hevner, A., Chatterjee, S.: Design research in information systems: theory and practice. Springer Science & Business Media (2010)
28. Peffers, K., Tuunanen, T., Rothenberger, M.A., Chatterjee, S.: A design science research methodology for information systems research. Journal of management information systems 24, 45-77 (2007)
29. Liapis, C., Chatterjee, S.: On a NeuroIS design science model. Service-Oriented Perspectives in Design Science Research, pp. 440-451. Springer (2011)
30. Dimoka, A., Banker, R.D., Benbasat, I., Davis, F.D., Dennis, A.R., Gefen, D., Gupta, A., Ischebeck, A., Kenning, P.H., Pavlou, P.A., M, G., #252, ller-Putz, Ren, #233, Riedl, Brocke, J.V., Weber, B.: On the use of neurophysiological tools in is research: developing a research agenda for neurois. MIS Q. 36, 679-702 (2012)
31. Riedl, R., Banker, R.D., Benbasat, I., Davis, F.D., Dennis, A.R., Dimoka, A., Gefen, D., Gupta, A., Ischebeck, A., Kenning, P.: On the foundations of NeuroIS: reflections on the Gmunden Retreat 2009. Communications of the Association for Information Systems 27, 15 (2010)
32. Brocke, J.V., Riedl, R., Léger, P.-M.: Application strategies for neuroscience in information systems design science research. Journal of Computer Information Systems 53, 1-13 (2013)
33. Loos, P., Riedl, R., Müller-Putz, G.R., Vom Brocke, J., Davis, F.D., Banker, R.D., Léger, P.-M.: NeuroIS: neuroscientific approaches in the investigation and development of information systems. Business & Information Systems Engineering 2, 395-401 (2010)
34. Riedl, R., Randolph, A.B., vom Brocke, J., Léger, P.-M., Dimoka, A.: The potential of neuroscience for human-computer interaction research. SIGHCI 2010 Proceedings (2010)

35. Vom Brocke, J., Riedl, R., Léger, P.-M.: Neuroscience in design-oriented research: exploring new potentials. Service-Oriented Perspectives in Design Science Research, pp. 427-439. Springer (2011)
36. Chatterjee, A.: Neuroaesthetics: a coming of age story. Journal of Cognitive Neuroscience 23, 53-62 (2011)
37. Leder, H., Belke, B., Oeberst, A., Augustin, D.: A model of aesthetic appreciation and aesthetic judgments. British journal of psychology 95, 489-508 (2004)
38. Chatterjee, A.: Prospects for a cognitive neuroscience of visual aesthetics. Bulletin of Psychology and the Arts 4, 6 (2004)

Towards a general-purpose mobile brain-body imaging NeuroIS testbed

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Abstract. Navigating (familiar) environments requires spatial memory and spatial orientation. Mobile information systems (IS) have largely taken on this task and have changed human behavior. What impact has the redistribution of problem solving on human skills and knowledge? We are interested in exploring how the use of IS impacts on knowledge/ignorance by means of mobile brain-body imaging. In this paper, we introduce a novel experimental testbed developed to study spatial orientation in the context of geographic maps. Key system features include data synchronization between various devices and data sources, flexibility in designing and modeling research questions and integration of online co-adaptive brain-computer interfacing (BCI) technology. Flexibility, adaptability, scalability and modifiability of the implemented system turn the testbed into a general-purpose tool for studying NeuroIS constructs.

Keywords: Mobile Brain and Body imaging • spatial orientation • general-purpose experiment environment • Brain-Computer Interface.

1 Introduction

Information systems (IS) and mobile devices allow accessing information and knowledge everywhere and at any time. The use of new and modern technology, hence, supports our knowledge-based society in freeing cognitive resources. People are enabled to focus on more important things. The downside of using IS is the vast amount of information available that challenges the limited capacity of our working memory. Cognitive resources are required to understand and evaluate the provided information, and to put it into the context of the current issue. Information can be blessing or curse. Accordingly, views vary on whether or not the use of IS leads to a society of knowledge or ignorance. In the former case, information is converted into new knowledge. In the latter case, information becomes a consumer product. Worst case, given the fact that information can be true or false, information is blindly trusted.

Dealing with new tools and technologies is a skill that involves learning. The learning process leads to changes in human behavior, which in turn induces changes in the brain. Mobile navigation devices, for example, help finding the fastest route to a destination. Users can focus on driving. The result is safer driving. The shift of attention towards driving and interaction with the technology prevents users from the acquisition of new spatial knowledge [1]. However, not using brain areas related to spatial orientation may lead to synaptic pruning. For example, licensed London taxi drivers know the city plan inside and out and have exceptional navigation skills. These abilities are associated with an enlargement of posterior hippocampi [2, 3]. Shrinking hippocampus on the other hand signals early Alzheimer's disease [4]. One may conclude that frequent users of navigation devices (or computer games [5]) could be at increased risk of developing neurological disorders during their lifetime.

We are interested in studying neural mechanisms of decision making and application of learned understanding associated with the use of IS. In order to do this, an experimental testbed is essential that allows acquiring behavioral and neural data from people while they are engaged in tasks that require interaction with IS. This data allows for brain-body imaging [6]. What is essential is that the experimental setup is as realistic as possible and that persons are enabled to interact and behave naturally [6, 7]. Motivated by the above example of spatial navigation, our current aim is to study non-invasive electroencephalogram (EEG) correlates of spatial orientation [7, 8] in the context of geographical maps by addressing the following scientific questions: Is knowledge and education of map-reading abilities represented in EEG dynamics? Are EEG dynamics of people experienced with topographic maps different when compared to persons that are inexperienced? What is the EEG dynamics situation in persons that mainly count on mobile IS for navigation? In this paper, after reviewing the relevant literature and formulating hypotheses, we present the experimental paradigm and introduce the testbed developed to address these questions.

2 EEG correlates of spatial orientation

Animal studies provided evidence that the hippocampus contains our own internal, spatial map. Particular neurons fire as function of location (place cells), distance (grid cells in the entorhinal cortex) or direction (head direction cells). Hippocampus, together with retrosplenial complex (RSC) and medial parietal cortex are brain structures that play a crucial role for spatial navigation and orientation. Functional magnetic resonance imaging (fMRI) studies confirmed that the above listed brain structures are involved in spatial navigation in humans as well [2, 3]. Activity in these structures even allows prediction of navigation performance [9-11]. Involved structures, however, are located under the cerebral cortex. It is still unclear to which extend the use of non-invasive EEG allows effective location and characterization of activity in these brain areas. The use of non-invasive mobile EEG compared to bulky and stationary fMRI technology, however, allows getting closer to reality, i.e., to natural behavior.

Our hypothesis is that people that score high on a spatial orientation test use less effort in finding coordinates on a map compared to persons that score low. Effort expenditure depends on task difficulty and motivation [12]. We believe to find differences in behavior (for example, task completion time or eye movement trajectories) and in EEG activity/connectivity patterns between the two groups. We anticipate that individuals with high scores will be able to solve the spatial orientation tasks efficiently, i.e., significantly quicker, compared to individuals with lower scores. The neural efficiency hypothesis suggests that more efficient brain functioning results in less and more focused activation [13]. This leads to the hypothesis that individuals that complete the spatial orientation tasks quickly and correctly also show reduced and more focused activity patterns compared to individuals that are not as efficient. Moreover, stronger phase locking between short-distant regions of the frontal cortex is expected in efficient performers [13].

Spatial navigation is a fundamental but complex cognitive function, which requires the integration and manipulation of multisensory information over time and space [14]. Accordingly, we can expect activity in widespread cortical networks while participants are engaged in a spatial orientation task. We hypothesize that occipital (visual information processing), parietal (sensory integration) and frontal lobes (memory and motor planning/control) show activation during the spatial orientation task when compared to a controlled rest condition. This hypothesis is based on recent findings in EEG. Motor-parietal cortical network activity was found in persons that performed an interactive gait task in a virtual environment [15, 7]. Activity in frontal cortex, motor cortex, parietal cortex, retrosplenial complex (RSC) and occipital cortex was found in persons that performed a path integration task in virtual reality [8]. In these studies, activity was reflected in task-related suppression, enhancement or modulation of theta (4-7 Hz), alpha (8-12 Hz), mu, beta (14-30 Hz) and gamma (> 30 Hz) rhythms.

Spatial navigation requires a spatial representation. Spatial reference frames (SRFs) can be either allocentric (object-to-object, relative distance between objects) or egocentric (self-to-object, relative distance from self to objects) [16]. The RSC plays a central role in this context [8]. It is not clear whether SRFs are relevant for interaction with topographic maps. The RSC, however, may be active when people estimate distances between positions on a map as required in our experiment.

3 Experimental paradigm

Theoretical and practical knowledge on geographical maps and spatial orientation skills will be assessed by a questionnaire we have developed. Individuals with highest and lowest scores are invited to participate in EEG recordings. Participants will be seated in front of a computer screen and asked to answer questions that require basic knowledge on longitude, latitude, cardinal points and the ability to estimate distances. To answer the questions participants will interact with an IS that provides interactive access to geospatial data. Possible questions include “Which city lies to the north-west of the following coordinates? 15.10 eastbound longitudes 47.40 northern latitudes?” Or “Which city is closer to the coordinates? 47.40 N, 15.10 E”. Note, that different types of questioning are used so that learned knowledge has to be applied. In the first experimental condition (condition interactive), participants have the task to correctly transfer global positioning system (GPS) coordinates into the IS, cognitively process the digital map (GPS coordinates are highlighted) and answer the question by clicking on one of two possible answers. In the second experimental condition (condition static) only a static image of a map is presented. Users have to find by themselves the given GPS coordinates and answer the question. User interaction is based on keyboard and mouse. Figure 1(a) shows screenshots of the user interface.

User behavior is quantified by recording keyboard and mouse input, the point of eye gaze (RED/SMI Eye Tracking Glasses 2.0, SensoMotoric Instruments GmbH, Germany), muscle signals (electromyogram, EMG) from both arms and events generated by the IS that enable reconstructing the user interaction. EEG is recorded by a mobile 64-channel EEG biosignal amplifier (eegosports, ANT-Neuro, Netherlands). The next section provides technical details about the IS developed for this study.

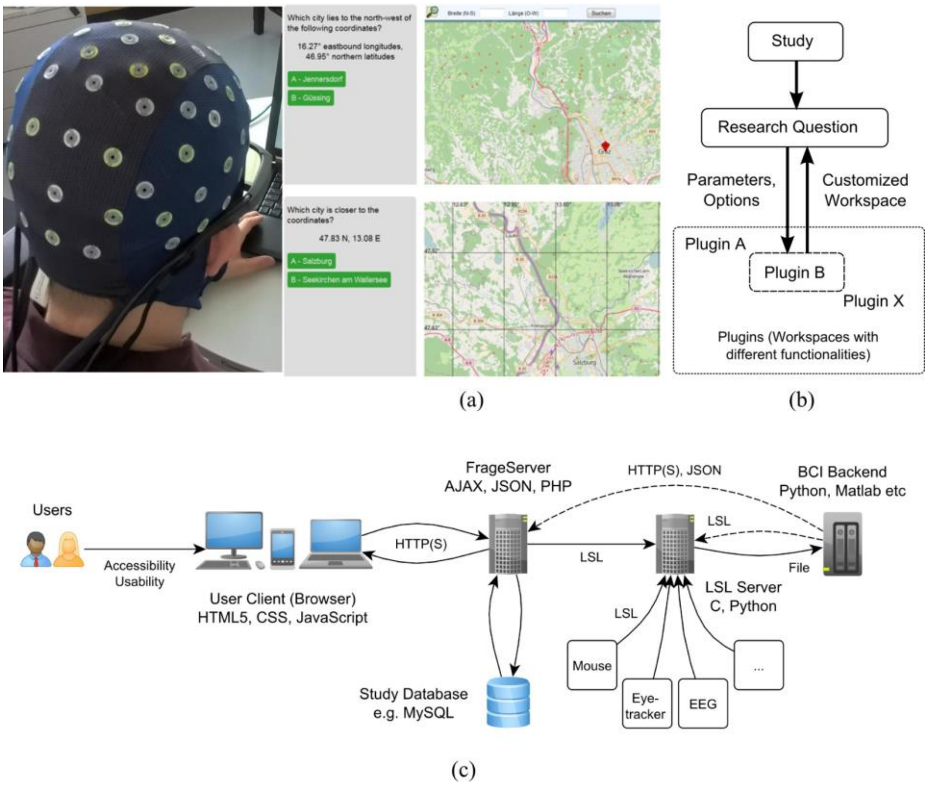

Figure 1. (a) Screenshots of the user interface for interactive (upper panel) and static (lower panel) experimental conditions. Questions and possible answers are presented in the left pane. Maps are visualized in the right pane. The search input box for the interactive condition is located above the map. (b) Hierarchical representation of studies. Plugins are workspaces that provide the functionality required for each behavioral task. (c) Overall system architecture. Components and when applicable applied technologies and protocols are shown (Lab Streaming Layer, LSL; Brain-Computer Interface, BCI). Arrows illustrate the data flow between components. Dashed lines illustrate online processing pathways. The picture shows a person participating in a spatial orientation pilot experiment. The user is wearing a cap with EEG sensors and an eye-tracker while answering questions as asked by the experimental paradigm.

4 Towards a general purpose framework

The system consists of two main components: the Lab Streaming Layer (LSL, [17]) for data synchronization, and the FrageServer for user interaction:

- LSL (available at `https://code.google.com/p/labstreaminglayer`) is a software system that allows collection and synchronization of data from a number of different (hardware) sources. LSL provides a network-based core transport layer as well as standalone hardware applications that utilize the layer to either make data available (e.g. data from EEG amplifier or eye-tracker) or retrieve data (e.g. data storage or online BCI processing). Available protocols and application programming interfaces allow easy expandability and integration of new sensors and devices [18].
- The FrageServer is a web-based client-server IS designed and developed to manage, plan, model and perform experiments. The platform is based on state-of-the-art technologies such as HTML5, CSS3, WCAG 2.0 Level AA, AJAX, JSON, PHP, and LSL, which ensure that the implemented server runs on current web servers and clients in modern browsers. This also ensures that the same interface and functionality paired with full accessibility is available across computer systems (from PC to smartphone).

Neuroscientific studies typically aim at answering one or more (N) research questions (Q_i, i=1...N). In this study, our question is whether or not persons with high and low spatial orientation skills have different EEG signatures. Two or more (M) behavioral tasks (T_j, j=1...M) are commonly needed to answer Q_i. We designed the interactive and static spatial interaction tasks. Since behavior varies, each task T_j has to be repeated a number of times (r=1...R). This hierarchical representation of study design was implemented into the FrageServer (see Figure 1(b)). Plugins represent different behavioral tasks T_j and deliver a customized workspace with functionalities required for solving the given task in the front-end of the FrageServer. Additionally, each plugin can be configured with different parameters and options for every repetition r. Two plugins were implemented for the spatial orientation study: the first plug-in allows users to enter GPS coordinates and visualize OpenStreetMap (OSM) data. The second plug-in displays a coordinate grid for given GPS coordinates in OSM (see Figure 1(a)). The type of questioning was defined for each repetition r individually.

The overall system architecture of the implemented testbed is shown in Figure 1(c). Users interact via the User Client with the FrageServer. Studies are stored in a database. The user interaction is streamed to the LSL server and synchronized with behavioral data (for example, keyboard, mouse, and eye-tracker) and biosignals (EEG). Any device that supports LSL can be included. The BCI backend performs online data processing. Note, that data from all LSL sources can be processed not only EEG. BCI output is sent to the FrageServer to either provide feedback to the user (for example, BCI control and communication experiments) or to modify task parameters (for example, task difficulty changes as a function of workload or affective state). Additionally, BCI output is streamed to the LSL server.

5 Discussion and outlook

The search for neural correlates of spatial orientation led to the development of a general-purpose testbed for studying neuroscientific research questions and exploring neuro IS constructs (for example, human-computer interaction, trust/distrust, affective computing, decision making). By using state-of-the-art technologies our system runs on nearly every device with network connection. The modular architecture and the implemented plugin system allows for simple adaptation of existing and integration of new behavioral tasks. Basic plugins allow visualization of images or websites. Other workspaces such as movie player or drawing canvas can be integrated with little effort. The use of LSL allows for easy scaling of the sensor network and integration of various IS without the need of additional coding. Note, that plugins may be used to collect data from devices that do not support LSL. Since we are also working with users with functional disabilities (e.g. [19]) accessibility (e-inclusion) is important.

First pilot experiments were conducted successfully in laboratory setting with participants sitting in front of a laptop computer. Preliminary EEG analyses show meaningful results. As expected we found task-related activity over occipital, parietal and frontal cortex. However, more data has to be recorded and more in depth analyses have to be performed before specific conclusions can be made.

The selected hardware allows immediate switching from desk to mobile and ambulatory setting. Future experiments will require users to interact with mobile IS while moving freely in the environment. For example, users will have to walk to a specific destination in open space by using mobile navigation devices. Three-dimensional body movement tracking and audiovisual scene recording are needed to this end.

One issue when recording EEG while persons are in motion are bioelectrical muscle artifacts, which can produce misleading EEG signals or destroy them altogether. Recently, we made significant progress toward artifact reduction methods and the analysis of EEG while persons are in motion [15, 20-23].

We plan to conduct experiments where the tasks provided by the FrageServer change based on the user's mental state or behavioral parameters. For example, the complexity of the user interface will change based on the user's workload. Or, erroneous instructions will be given to users when they get closer (based on GPS coordinates) to the destination. These experiments allow us studying user interface design and trust issues. Since we have extensive experience with online EEG data analysis, BCI and online man-machine co-adaptation [20, 24-26] the next step is the implementation of the BCI backend functionality

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References

[1] Ishikawa, T. & Takahashi, K. Relationships between Methods for Presenting Information on Navigation Tools and Users ’ Wayfinding Behavior. Cartogr. Perspect. 75, 17–28 (2013).

[2] Woollett, K. & Maguire, E. A. Acquiring ‘the knowledge’ of London’s layout drives structural brain changes. Curr. Biol. 21, 2109–2114 (2011).

[3] Maguire, E. a, Gadian, D. G., Johnsrude, I. S., Good, C. D., Ashburner, J., Frackowiak, R. S. & Frith, C. D. Navigation-related structural change in the hippocampi of taxi drivers. Proc. Natl. Acad. Sci. U. S. A. 97, 4398–403 (2000).

[4] Henneman, W. J. P., Vrenken, H., Barnes, J., Sluimer, I. C., Verwey, N. A., Blankenstein, M. A., Klein, M., Fox, N. C., Scheltens, P., Barkhof, F. & Van Der Flier, W. M. Baseline CSF p-tau levels independently predict progression of hippocampal atrophy in Alzheimer disease. Neurology 73, 935–940 (2009).

[5] West, G. L., Drisdelle, B. L., Konishi, K., Jackson, J., Jolicoeur, P. & Bohbot, V. D. Habitual action video game playing is associated with caudate nucleus- dependent navigational strategies. Proc. R. Soc. London B Biol. Sci. 282, 20142952 (2015).

[6] Makeig, S., Gramann, K., Jung, T.-P., Sejnowski, T. J. & Poizner, H. Linking brain, mind and behavior. Int. J. Psychophysiol. 73, 95–100 (2009).

[7] Ehinger, B. V, Fischer, P., Gert, A. L., Kaufhold, L., Weber, F., Pipa, G. & König, P. Kinesthetic and vestibular information modulate alpha activity during spatial navigation: a mobile EEG study. Front. Hum. Neurosci. 8, 71 (2014).

[8] Lin, C.-T., Chiu, T.-C. & Gramann, K. EEG correlates of spatial orientation in the human retrosplenial complex. Neuroimage 120, 123–132 (2015).

[9] Sulpizio, V., Boccia, M., Guariglia, C. & Galati, G. Functional connectivity between posterior hippocampus and retrosplenial complex predicts individual differences in navigational ability. Hippocampus (2016). doi:10.1002/hipo.22592

[10] Baumann, O. & Mattingley, J. B. Medial parietal cortex encodes perceived heading direction in humans. J. Neurosci. 30, 12897–901 (2010).

[11] Chadwick, M. J., Jolly, A. E. J., Amos, D. P., Hassabis, D. & Spiers, H. J. A goal direction signal in the human entorhinal/subicular region. Curr. Biol. 25, 87–92 (2015).

[12] Brehm, J. W. & Self, E. A. The intensity of motivation. Annu. Rev. Psychol. 40, 109–31 (1989).

[13] Neubauer, A.C., Fink, A.: Intelligence and neural efficiency: Measures of brain activation versus measures of functional connectivity in the brain. Intelligence. 37, 223–229 (2009).

[14] Wolbers, T., Hegarty, M.: What determines our navigational abilities? Trends Cogn. Sci. 14, 138–46 (2010).

[15] Wagner, J., Solis-Escalante, T., Scherer, R., Neuper, C. & Müller-Putz, G. R. It’s how you get there: walking down a virtual alley activates premotor and parietal areas. Front. Hum. Neurosci. 8, 93 (2014).

[16] Klatzky, R.L.: Allocentric and Egocentric Spatial Representations: Definitions, Distinctions, and Interconnections. 1–18 (1998).

[17] Delorme, A., Mullen, T., Kothe, C., Akalin Acar, Z., Bigdely-Shamlo, N., Vankov, A. & Makeig, S. EEGLAB, SIFT, NFT, BCILAB, and ERICA: New tools for advanced EEG processing. Comput. Intell. Neurosci. 2011, (2011).

[18] Schlesinger, M. An LSL-Based Sensor Platform for Mobile Brain Imaging, Brain-Computer Interfaces and Rehabilitation (Master's thesis) (2016)

[19] Scherer, R., Billinger, M., Wagner, J., Schwarz, A., Hettich, D. T., Bolinger, E., Lloria Garcia, M., Navarro, J. & Müller-Putz, G. R. Thought-based row-column scanning com-

munication board for individuals with cerebral palsy. Ann. Phys. Rehabil. Med. (2015). doi:10.1016/j.rehab.2014.11.005

[20] Daly, I., Scherer, R., Billinger, M. & Müller-Putz, G. R. FORCe: Fully Online and automated artifact Removal for brain-Computer interfacing. IEEE Trans. Neural Syst. Rehabil. Eng. (2014). doi:10.1109/TNSRE.2014.2346621

[21] Wagner, J., Solis-Escalante, T., Grieshofer, P., Neuper, C., Müller-Putz, G. R. & Scherer, R. Level of participation in robotic-assisted treadmill walking modulates midline sensorimotor EEG rhythms in able-bodied subjects. Neuroimage 63, 1203–11 (2012).

[22] Scherer, R., Moitzi, G., Daly, I. & Müller-Putz, G. R. On the Use of Games for Noninvasive EEG-Based Functional Brain Mapping. IEEE Trans. Comput. Intell. AI Games 5, 155–163 (2013).

[23] Seeber, M., Scherer, R., Wagner, J., Solis-Escalante, T. & Müller-Putz, G. R. EEG beta suppression and low gamma modulation are different elements of human upright walking. Front. Hum. Neurosci. 8, 485 (2014).

[24] Pfurtscheller, G., Müller-Putz, G. R., Schlögl, A., Graimann, B., Scherer, R., Leeb, R., Brunner, C., Keinrath, C., Lee, F. Y., Townsend, G., Vidaurre, C. & Neuper, C. 15 years of BCI research at Graz University of Technology: current projects. IEEE Trans. Neural Syst. Rehabil. Eng. 14, 205–10 (2006).

[25] Scherer, R., Müller-Putz, G. R. & Pfurtscheller, G. Flexibility and practicality: The Graz Brain-Computer Interface approach. Int. Rev. Neurobiol. 86, 119–31 (2009).

[26] Faller, J., Vidaurre, C., Solis-Escalante, T., Neuper, C. & Scherer, R. Autocalibration and recurrent adaptation: Towards a plug and play online ERD-BCI. IEEE Trans. Neural Syst. Rehabil. Eng. 20, 313–319 (2012).

Differences in Reading between Word Search and Information Relevance Decisions – Evidence from Eye-tracking

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Abstract: We investigated differences in reading strategies in relation to information search task goals and perceived text relevance. Our findings demonstrate that some aspects of reading when looking for a specific target word are similar to reading relevant texts to find information, while other aspects are similar to reading irrelevant texts to find information. We also show significant differences in pupil dilation on final fixations on relevant words and on relevance decisions. Our results show feasibility of using eye-tracking data to infer timing of decisions made on information search tasks in relation to the required depth of information processing and the relevance level.

Keywords: Information search, reading, relevance, eye-tracking, pupillometry.

1 Introduction and Related Work

Relevance assessment is one of fundamental cognitive actions performed by humans. Business Dictionary defines relevant information as "*Data which is applicable to the situation or problem at hand that can help solve a problem or contribute to a solution*" [1]. This could be in the context of just about any human task, including an ecommerce transaction. Information relevance has been conceptualized in information systems literature as a component of information quality and has been shown to contribute positively to decision-making satisfaction [2]. It also has been shown to be a critical antecedent of willingness to disclose information [3, 4]. In information retrieval systems (aka search engines) area, there is a tendency to view relevance from the system-centered perspective and consider it a binary construct that can be measured algorithmically. Operationalization of this simple view has led to the world-wide success of search engines. Yet, many scholars have been discontent with such simplified notion of relevance and over the last four decades [5] efforts in theorizing relevance as a multi-dimensional, multi-stage and multi-valued concept continued [6–10]. We contribute to these efforts by bringing neuro-physiological methods to investigating cognitive aspects of relevance. We have previously reported our earlier studies, including an fMRI study that examined differences in brain activations between reading relevant and irrelevant texts [11] and an eye-tracking study, in which we showed measures correlated with processing of relevant and irrelevant texts [12, 13]. In this paper we present a new analysis of eye-tracking data with a focus on reading strategies on tasks with word search targets which we contrast with strategies on tasks with information search goals. The presented analysis uses pupil data in addition to eye fixation measures.

Related Work. We selectively review only a few works that employed eye-tracking in investigating information relevance. Ajanki et al. [14] used eye-movement based features as implicit relevance feedback. They found regressions and relative duration of the first fixation on a word to be important features and demonstrated that information retrieval system's performance could be improved modestly by using eye-based features to select additional query terms. Not relevant documents were shown to impose lower mental load than relevant ones [12]. Buscher at el. [15] demonstrated a relationship between several eye movement measures and text passage relevance. They found the length of coherently read text to be the strongest relevance indicator. Fixation duration was not an effective discriminator between relevant and not relevant text. The reading eye movement measures were used to improve relevance ranking by ~8% overall. For queries with poor search results, the improvement was 27%. Simola et al. [16] used eye movement features to improve classification of processing states on three simulated information search tasks (word search, question-answer, and subjective interest) to 60.2%. Their work used simple search tasks and single sentences rather than text paragraphs.

Most eye-trackers measure pupil dilation and this variable is also of interest to our work. Pupil dilation is controlled by the Autonomic Nervous System (ANS) [17]. Under constant illumination it has been associated with a number of cognitive functions, including mental workload [18], interest [19], surprise [20], and making decisions [21]. It is reasonable to expect that document relevance will affect level of attention or mental workload and, thus, pupil size. Only few published works examined pupil size in relation to information relevance. In [22] Oliveira et al. show reported that pupil dilated for higher relevance stimuli for text documents and images. In our earlier work on relevance of short text documents [12] and web pages [23] we showed significant pupil dilation on relevant documents and, in particular, in the one or two second period preceding relevance decision.

In this work we extend previous results by investigating how differences in reading documents that result from user tasks (locating a word and finding required information) and varying information relevance are reflected in measures obtained from eye-tracking. Our research questions are as follows: *RQ1*. Do people read differently when locating a target word as compared to when finding required information? *RQ2*. Does pupil dilation differ between the two cases?

2 Method

We conducted a controlled lab experiment, in which participants (N=24; 9 females) were asked to find information in short text documents containing news stories. Participants were recruited from undergraduate and graduate student body at Rutgers

University in New Jersey, USA. The experiment was conducted in a usability lab equipped with Tobii T-60 remote eye-tracker. The within-subjects experimental design (shown in Figure 1) is essentially the same as reported at NeuroIS'2014 [13]; we describe it briefly below. Each participant performed two types of tasks, word search (W task), and a question-prompted information search (I task). In both tasks search was performed in short news stories (mean length 178(30) words) selected from a large set obtained from the AQUAINT corpus [24]. Each session included 21 pseudo-randomized trials of each task type, as well as a few training trials. In W task, a trial comprised a target word presentation followed by a text that contained the target word. Each document contained exactly one target word; locating it required orthographic matching without the need for semantic processing [25]. Participants responded by pressing a key as soon as they located the target word. In I task, a trial consisted of question that instructed participants what information they were expected to find in one or more of the subsequently presented three news stories of varied relevance: *irrelevant* (*I*), *partially relevant* texts that were on a question's topic, but did not contain the answer (*T*), and *relevant* texts that contained the answer (*R*). Participants responded by judging document relevance of sixty-three news stories on a binary scale (yes/no). In contrast to W task, making relevance decisions in I task required semantic processing. The order of trials in both tasks and the order of text relevance in I task, were randomized. We previously reported [12, 13] earlier results from eye-tracking data analysis for I task only; in this paper we present new analysis that compares task W with I.

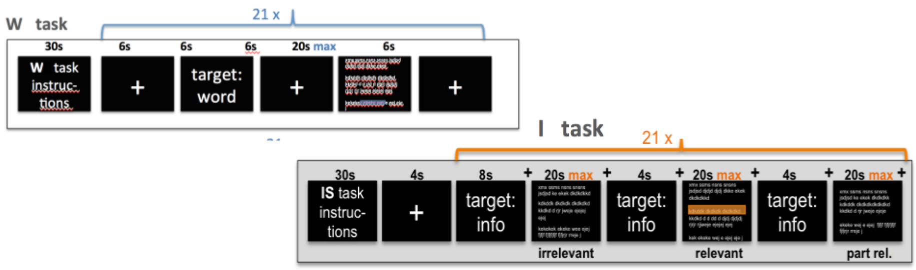

Fig. 1. Experimental Design

Dependent variables derived from eye-tracking data included two groups: 1) eye fixation variables obtained by modeling reading as a two-state process (RM-Eye variables), and 2) relative pupil dilation (RPD). Our approach to modeling reading is influenced by EZ-Reader model [26] and we have previously reported its details [13, 27]. Our reading model is line-oriented and consists of two states, a) reading state represents continuous reading in one line; reading in a subsequent line is represented by a new reading state; b) scanning state represents isolated fixations. Fixations are labeled as belonging to *reading* or *scanning*; before labeling, non-lexical fixations (<150ms) are removed. Variables obtained from the reading model included probabilities of remaining in a scanning (pSS) or reading state (pRR), counts and durations of reading and scanning states and fixations. The controlled lab environment, consistent use of text documents with black background and a similar number of words presented in white font ensured virtually no variability of luminance across all trials and thus no resulting changes in pupil dilation. To eliminate individual variability in pupil sizes, we calculated a baseline for each participant (i) by taking an average pupil size over all text document presentations ($P^{i}_{baseline}$) and calculating relative change in pupil dilation (RPD^{i}_{t}) from pupil measurement at a time t P_t as shown in equation (1).

$$RPD^{i}_{t} = (P_t - P^{i}_{baseline}) / \underline{P}^{i}_{baseline} \quad (1)$$

Mean values of *RPD* were calculated on each trial in three one-second-long epochs: 1) epochs starting at the first fixation on a relevant word, 2) the last fixation on a relevant word; and 3) epochs at the end of trials, that is, when participants were making relevance decisions. To avoid a possible influence of motor actions, the last 200ms of a trial was not included.

Independent variables included, task type (W or I) and a participant's relevance judgment (*perceived relevance: **I**rrelevant or **R**elevant*).

Eye-tracking data was cleaned by removing bad quality fixations and those outside screen. This process resulted in removal of ~5% of fixations. Raw pupil data was denoised using Daubechies D4 level 4 wavelet transform, then algorithm adapted from [28] was used to detect blinks and replace missing data with cubic splines.

3 Data Analysis and Results

The overall accuracy of participants' relevance judgments was quite high at 90.3% and we concluded that participants performed it according to our expectation. In our analysis, we only considered data from trials with correct responses. Due to not-normal distribution of RM-Eye variables, we analyzed them using non-parametric Kruskal-Wallis test. A three level factor was constructed by combining two-level of task types with two-levels of document relevance judgment (applicable only to I task) (**Table 1**). Relative pupil dilation was distributed normally, and thus we analyzed the effects of tasks and the three-level factor using one-way ANOVA (**Table 2**).

Table 1. Differences in RM-Eye variables between tasks and texts (mean(SD)).

	W Task	I Task - R	I Task - I	K-W $\chi^2(2)$
Time to complete [s]	8.4(4.4)	9.7(4.2)	9.6(4.6)	17.26****
pSS	0.42(0.25)	0.37(0.27)	0.50(0.26)	39.27****
pRR	0.87(0.11)	0.89(0.09)	0.81(0.12)	114.38****
Fixation count on words	26(16)	32(17)	31(17)	20.65****
Count of reading fixations	21.8(14.2)	26.9(15.7)	23.8(16.2)	17.86****
Count of scanning fixations	5.8(4.7)	5.3(3.9)	8.3(5.1)	105.13****
Total reading duration [s]	5.4(3.4)	6.6(3.7)	5.8(3.9)	18.96****
Total scanning duration [s]	1.6(1.4)	1.4(1.0)	2.3(1.4)	104.67****

* p<0.05, ** p<0.01, *** p<0.001, **** p<0.0001

Table 2. Differences in relative pupil dilation between tasks (mean(SD)) [%].

Epoch (1s)	W Task	I Task	ANOVA
relevance decision	0.63 (5.5)	1.02 (5.4)	F(1,980) = 1.09

Table 3. Differences in relative pupil dilation for three level factor (mean(SD)) [%].

Epoch (1s)	W Task	I Task–R	I Task–I	ANOVA
first relevant word	0.35 (5.4)	0.86 (5.1)	n/a	$F(1,393) = 0.92$
last relevant word	1.05 (5.6)	2.82 (5.0)	n/a	$F(1,393)$ [1] $= 11.05^{***}$
relevance decision	0.63 (5.5)	3.09 (4.9)	-0.08 (5.3)	$F(2,979)$ [2] $= 27.41^{****}$

[1] Due to lack of homogeneity of variance for this variable, we report Brown-Forsythe robust test of equality of means.
[2] Post hoc analysis (Games-Howell) indicated a significant difference between I task–R and other conditions; there was no significant difference between W task and I task–I. Statistical significance is marked by: *** $p<0.001$, **** $p<0.0001$

4 Discussion and Conclusions

Our results demonstrate differences in reading when locating a target word (W task) as compared to when finding required information (I task) (*RQ1*). Overall, on W task participants were faster and had fewer fixations than on I task. Time spent scanning on W task was about the same as scanning time on relevant texts on I task and lower than scanning time on irrelevant texts on I task. In contrast, time spent reading on W task was similar to reading time on irrelevant texts on I task and lower than reading time on relevant texts on I task. At the same time, the tendency to keep reading on W task was about the same as on relevant texts on I task and both were higher than on irrelevant texts in I task. The tendency to keep scanning was highest on irrelevant documents on I task, as was the number of scanning fixations. These results show a clearly different reading pattern for each of the investigated conditions.

Even more interesting are our findings on pupil dilation (*RQ2*). We found no difference in pupil dilation between the two tasks during the relevance decision epoch (**Table 2**). However, we found significant differences when considering text relevance on I task (**Table 3**). Pupil dilation during relevance decisions on relevant texts on I task was significantly higher (3.09%) than on W task (0.63%) and on irrelevant texts on I task (-0.08%). Furthermore, pupil dilation during the last fixations on relevant words was significantly higher on relevant texts on I task (2.82%) than on W task (1.05%). These results indicate, plausibly, that relevance decisions that involve semantic processing (I task) are of different nature than decisions that involve orthographic processing (W task) and that this difference can be inferred from changes in pupil dilation.

Practical implication of our results is that they indicate a feasibility of using eye-tracking data to infer timing of decisions made on search tasks in relation to the required depth of information processing and the relevance level. Analysis presented in this paper was at the aggregate level of all participants. In future work, we plan to perform analysis for individual participant. We also plan to conduct more detailed analysis of pupillary responses.

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References

1. Business Dictionary: relevant information, http://www.businessdictionary.com/definition/relevant-information.html.
2. Bharati, P., Chaudhury, A.: An empirical investigation of decision-making satisfaction in web-based decision support systems. Decis. Support Syst. 37, 187–197 (2004).
3. Zimmer, J.C., Arsal, R.E., Al-Marzouq, M., Grover, V.: Investigating online information disclosure: Effects of information relevance, trust and risk. Inf. Manage. 47, 115–123 (2010).
4. Li, H., Sarathy, R., Xu, H.: The role of affect and cognition on online consumers' decision to disclose personal information to unfamiliar online vendors. Decis. Support Syst. 51, 434–445 (2011).
5. Saracevic, T.: RELEVANCE: A review of and a framework for the thinking on the notion in information science. J. Am. Soc. Inf. Sci. 26, 321–343 (1975).
6. Huang, X., Soergel, D.: Relevance: An improved framework for explicating the notion. J. Am. Soc. Inf. Sci. Technol. 64, 18–35 (2013).
7. Borlund, P.: The concept of relevance in IR. J. Am. Soc. Inf. Sci. Technol. 54, 913–925 (2003).
8. Zhang, Y., Zhang, J., Lease, M., Gwizdka, J.: Multidimensional Relevance Modeling via Psychometrics and Crowdsourcing. In: Proceedings of the 37th International ACM SIGIR Conference on Research and Development in Information Retrieval. pp. 435–444. ACM, New York, NY, USA (2014).
9. da Costa Pereira, C., Dragoni, M., Pasi, G.: Multidimensional relevance: Prioritized aggregation in a personalized Information Retrieval setting. Inf. Process. Manag. 48, 340–357 (2012).
10. Cosijn, E., Ingwersen, P.: Dimensions of relevance. Inf. Process. Manag. 36, 533–550 (2000).
11. Gwizdka, J.: Looking for Information Relevance In the Brain. In: Gmunden Retreat on NeuroIS 2013. p. 14. , Gmunden, Austria (2013).
12. Gwizdka, J.: Characterizing Relevance with Eye-tracking Measures. In: Proceedings of the 5th Information Interaction in Context Symposium. pp. 58–67. ACM, New York, NY, USA (2014).
13. Gwizdka, J.: Tracking Information Relevance. In: Gmunden Retreat on NeuroIS 2014. p. 3. , Gmunden, Austria (2014).
14. Ajanki, A., Hardoon, D., Kaski, S., Puolamäki, K., Shawe-Taylor, J.: Can eyes reveal interest? Implicit queries from gaze patterns. User Model. User-Adapt. Interact. 19, 307–339 (2009).
15. Buscher, G., Dengel, A., Biedert, R., Elst, L.V.: Attentive documents: Eye tracking as implicit feedback for information retrieval and beyond. ACM Trans Interact Intell Syst. 1, 9:1–9:30 (2012).
16. Simola, J., Salojärvi, J., Kojo, I.: Using hidden Markov model to uncover processing states from eye movements in information search tasks. Cogn. Syst. Res. 9, 237–251 (2008).
17. Onorati, F., Barbieri, R., Mauri, M., Russo, V., Mainardi, L.: Characterization of affective states by pupillary dynamics and autonomic correlates. Front. Neuroengineering. 6, 9 (2013).

18. Kahneman, D., Beatty, J.: Pupil Diameter and Load on Memory. Science. 154, 1583–1585 (1966).
19. Krugman, H.E.: Some applications of pupil measurement. JMR J. Mark. Res. Pre-1986. 1, 15 (1964).
20. Preuschoff, K., Hart, B.M. ’t, Einhäuser, W.: Pupil dilation signals surprise: evidence for noradrenaline’s role in decision making. Front. Decis. Neurosci. 5, 115 (2011).
21. Einhäuser, W., Koch, C., Carter, O.L.: Pupil Dilation Betrays the Timing of Decisions. Front. Hum. Neurosci. 4, (2010).
22. Oliveira, F.T.P., Aula, A., Russell, D.M.: Discriminating the relevance of web search results with measures of pupil size. In: Proceedings of the 27th international conference on Human factors in computing systems. pp. 2209–2212. ACM, Boston, MA, USA (2009).
23. Gwizdka, J., Zhang, Y.: Differences in Eye-Tracking Measures Between Visits and Revisits to Relevant and Irrelevant Web Pages. In: Proceedings of the 38th International ACM SIGIR Conference on Research and Development in Information Retrieval. pp. 811–814. ACM, New York, NY, USA (2015).
24. Graff, D.: The AQUAINT Corpus of English News Text. (2002).
25. Léger, L., Rouet, J.-F., Ros, C., Vibert, N.: Orthographic versus semantic matching in visual search for words within lists. Can. J. Exp. Psychol. Rev. Can. Psychol. Expérimentale. 66, 32–43 (2012).
26. Reichle, E.D., Pollatsek, A., Rayner, K.: EZ Reader: A cognitive-control, serial-attention model of eye-movement behavior during reading. Models Eye-Mov. Control Read. 7, 4–22 (2006).
27. Cole, M.J., Gwizdka, J., Liu, C., Bierig, R., Belkin, N.J., Zhang, X.: Task and user effects on reading patterns in information search. Interact. Comput. 23, 346–362 (2011).
28. Mathôt, S.: A simple way to reconstruct pupil size during eye blinks, http://dx.doi.org/10.6084/m9.figshare.688001, (2013).

The influence of task characteristics on multiple objective and subjective cognitive load measures

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Abstract. Using Electroencephalography (EEG), this study aims at extracting three features from instantaneous mental workload measure and link them to different aspect of the workload construct. An experiment was designed to investigate the effect of two workload inductors (Task *difficulty* and *uncertainty*) on extracted features along with a subjective measure of mental workload. Results suggest that both subjective and objective measures of workload are able to capture the effect of task *difficulty*; however only accumulated load was found to be sensitive to task *uncertainty*. We discuss that the three EEG measures derived from instantaneous workload can be used as criteria for designing more efficient information systems.

1 Introduction

Measuring the mental workload construct has been a challenge to researchers in different fields [1,2,3]. This construct has either been assessed subjectively with self-reported measures or objectively with measures such as electroencephalography (EEG). Subjective workload measures prevent us from understanding the multiple variations of workload during a task and are subject to a retrospective bias. The use of neurophysiological workload measures can alleviate these shortcomings to some extent [4]. Researchers have compared subjective and objective mental workload and suggested that objective measures can provide a more comprehensive and richer understanding of the workload construct [5, 6].
However, thus far, research has only used one of many possible measures of objective workload when comparing it to subjective workload [7]. Given that multiple measures of objective workload can be extracted from EEG signals (e.g., *Average load, Accumulated load, and Number of peaks*), an even richer understanding of cognitive load could be attained. Thus, the objective of this research is to investigate the relationships between multiple objective workload measures and a subjective workload measure. In addition, it aims at better understanding the effects of task characteristics (i.e., uncertainty and difficulty) on these different workload measures.

2 Literature Review

Researchers from various disciplines have been interested in studying cognitive workload [8,9], such as understanding the consequences of various workload levels on user performance [10]. Mental workload can be defined as “the set of mental resources that people use to encode, activate, store, and manipulate information while they perform a cognitive task” [11] . Researchers study cognitive load in order to prevent people from experiencing high mental workload and its negative consequences, such as frustration, negative affect, or mental fatigue [12]. Lower cognitive load has also been related to users’ satisfaction with online task [13].

Generally, there are three types of cognitive load measures: subjective, performance, and physiological [14,15]. Subjective measures, which are the most mature ones, have been used for many years to study users’ behavior [16]. Borrowing from neuroscience and neuropsychology, researchers in social science have started to use physiological metrics to measure cognitive load [13]. Researchers have developed several algorithms based on EEG signals to calculate mental workload metrics [17]. EEG signals are high dimensional noisy time series, which encompass a high volume of information [18]. In order to relate such signals to specific mental states (e.g., mental workload), first of all noise should be removed from the signal, and more importantly, relevant signal features should be selected that represent the desired mental state [19]. In this study, we use education literature to define three features of instantaneous workload measure.

Xie and Salvendy [7] defined four types of workload: peak load, average load, accumulated load, and overall load. Instantaneous load shows the dynamics of cognitive load over time. Peak load is the maximum load an individual experiences during a task, while accumulated load is the summation of all the cognitive load. Average load reflects the mean load an individual experience in performing a task, and overall load is the self-perceived load [7]. Figure 1 illustrates how peak load, accumulated load, and average load are related to instantaneous load. Despite the fact that all workload measures represent users’ cognitive load level, they are different. Average load is an overall measure which represents mostly the amount of cognitive resources that a task requires on average. Accumulated load provides the whole amount of load that is experienced taking into account the average and the time dimensions. Therefore, it is a more comprehensive measure of workload. Another type of information that cannot be obtained using a subjective measure, average, or accumulated load is the maximum load. We know from the literature that our cognitive capacity is limited [10] and it has a red line for information processing [20]. Other workload measures do not indicate if users have experienced such red lines. This information can be useful for studying users’ coping behavior with high workload situations. For instance, if users experience high cognitive load during a difficult task they might withdraw from the task [21]. Peak load may be the proper criteria to study such behaviors.

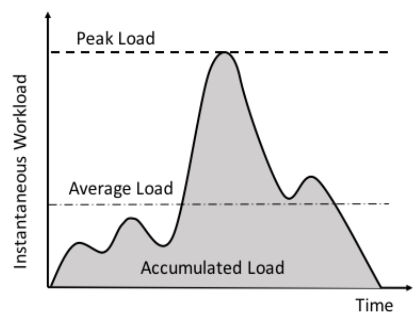

Figure 1- Workload Features

3 Hypotheses

Tasks characteristics are an important factor in predicting users' cognitive load. In general, any factor that renders decision making more difficult will impose more load on cognitive resources. For instance, research suggests that mathematical complexity and arithmetic operations increase users' mental workload [9]. Therefore, task difficulty will affect users' mental workload.

H1: Task difficulty is positively associated with all workload types (Overall, Average, Accumulated, Peak).

Information processing includes three stages: information perception, decision/response selection, and response execution [7]. Any factor that impairs this process may force individuals to use more cognitive resources in order to fulfill decision requirements. Information uncertainty affects the first stage by making it more difficult for users to assess the critical information required for making product decisions, which consequently imposes more cognitive load on users. A number of studies have found evidence of such effect [22]**.**

H2: Task uncertainty is positively associated with all workload types (Overall, Average, Accumulated, Peak).

4 Methodology

4.1 Experimental Design

To test our hypotheses, a 2 (low or high task *difficulty*) X 2 (low or high task *uncertainty*) within-subject experiment was used. This experiment got the approval by our Institutional Review Board (IRB). Ten subjects participated in the experiment and 50% were male. Each subject performed all four tasks (one per condition) which were randomly ordered. For each task, participants had to shop on a selected online grocery website. The task started on an online grocery recipe page. Participants were instructed shop for five given items for each assigned recipe. After finishing each task, subjects completed a questionnaire. Online grocery is a suitable context for this study because it is a long user-IT transaction [23]. As opposed to other online shopping contexts which are mostly composed of singles product decisions. Online grocery usually includes several decisions and allows us to observe the dynamics of users' cognitive load. Moreover, there are a number of workload antecedents which are unique to this context such as performing simple arithmetic operations in order to find the right quantity of a product or the uncertainty involved in buying perishable products.

Task *difficulty* was manipulated by asking subjects to change the quantity of ingredients suggested for the recipe. Recipe pages suggested the right amount of each grocery item to use for 4 people. In the low *task difficulty* condition, participants had to choose the same quantity and in the high *difficulty* condition, they were asked to perform simple arithmetic operations in order to find the right quantity of each ingredient for 20 people. We used product type (perishable or non-perishable) to manipulate task *uncertainty*. In the low *uncertainty* condition, participants had to shop for 5 specified non-perishable products (e.g., olive oil) and in the high *uncertainty* condition, they were instructed to shop for 5 specified perishable products (e.g., meat).

4.2 Measures

Overall load was measured using a five item scale developed by Cameron [24]. Instantaneous measure of cognitive load was measured using a linear EEG algorithm. In general, EEG oscillations are categorized into four frequency bands: Delta (0 to < 4 Hz), Theta (4 to < 8Hz), Alpha (8 to 13 Hz), and beta (>13 Hz) [25]. In this experiment, we use a linear algorithm to measure the cognitive load of users. This algorithm includes calculating the ((delta+theta)/alpha) power ratio over a moving 2 second window and compare it with the average of previous 20 seconds [17]. The average of users' workload over a task period was used as *Average load*. The area under the instantaneous workload curve which equals the sum of instantaneous load over time was used as *Accumulated load*. To calculate the *Peak load*, we counted the number of times that the amplitude of instantaneous load exceeded 2.5 standard deviations of the instantaneous load, indicating the number of times participants experienced nearly peak load.

4.3 Apparatus, Data Acquisition, and Analysis

EEG data was recorded using a 32 electrodes using EGI's dense array electroencephalography (dEEG). In order to test the hypotheses, we used a regression analysis with task *difficulty* and *uncertainty* as independent variables and mental workload (*Overall, Average, Accumulated, Peak loads*) as dependent variable. Since the observations are non-independent, we used regression analysis for repeated measures. We also controlled for learning effect by including the order in which participants performed the task into the model.

5 Results

H1 proposed that task *difficulty* is positively associated with all measures of mental workload. Results show significant relationships between *difficulty* and Overall load ($b= 0.88$, $p<0.01$), Average load ($b=0.02$, $p<0.05$), Accumulated load ($b=44.45$, $p<0.01$), number of Peaks ($b=4.87$, $p<0.05$). Therefore, H1 is supported. Our second hypothesis proposed that task *uncertainty* is an antecedent of all workload types. Regression results show that the relationships between *uncertainty* and Overall load ($b=0.51$, $p=0.18$), Average load ($b=0.01$, $p=0.15$), number of Peaks ($b=3.12$, $p=0.15$) are not significant. However, a significant result was found for the relationship between *uncertainty* and Accumulated load ($b=35.24$, $p<0.05$). Thus, H2 is partially supported.

6 Discussion

Our results suggest that all the extracted features of instantaneous load and the subjective measure of workload (i.e., Overall load) are sensitive to task *difficulty*; however only Accumulated load was able to capture the mental workload induced by task *uncertainty*. Based on the definition of Accumulated load, we can expect more comprehensiveness of this measure compared to Average load or Overall load. Accumulated load measures the change of users' instantaneous workload over time, thus accounting not only for overall load but also the total time that user has been performing the task. "Time on task" has been used as a measure for workload before [26], thus it may represent more dimensions of the workload construct.

To better understand the difference between workload measures, we conducted a post hoc analysis and compared the effect of task *difficulty* and *uncertainty* on each workload measure. We used four regression models with the same independent variables (Task *difficulty* and *uncertainty*) but with four different measures of workload as dependent variable (Overall, Accumulated, Average, and number of Peaks). Since the number of independent variables are the same, we can compared R-square across the regression models. Accumulated load explained more variance than other models (21%). It was followed by number of Peaks (16%), Overall load (14%), and Average load (5%). These results confirm our expectations that Accumulated load can capture more variability caused by workload inductors. Results also show a relatively high R-square for number of Peaks. In addition to being used as a workload measure, Peak load can also to identify the moments that users experience high workload. In other words, it is able to identify the exact time periods that users approach or pass the red line of their cognitive capacity. This type of information, which can only be gained using Peak load, may provide a proper lens to study users coping behavior in dealing with high workload situations.

7 Conclusion

Our analysis showed that Average load and overall load yield similar results while Accumulated load is a stronger indicator of the total workload experienced by users. Number of Peaks is also an appropriate metric to assess users' mental workload and study the consequences of experiencing high workload. Our results show that only Accumulated load was able to capture the effect of task *uncertainty*. Finally, Peak load can be used to analyze users' dynamic cognition. This research contributes to the literature by 1) introducing a mental workload feature extraction method in order to benefit from the richness of EEG data; 2) deriving three new metrics for measuring mental workload and explaining how these measures can be useful to study users' experience.

References

1. Gopher, D., Braune, R.: On the psychophysics of workload: Why bother with subjective measures? Hum. Factors J. Hum. Factors Ergon. Soc. 26, 519–532 (1984).
2. Paas, F., Sweller, J.: An Evolutionary Upgrade of Cognitive Load Theory: Using the Human Motor System and Collaboration to Support the Learning of Complex Cognitive Tasks. Educ. Psychol. Rev. 24, 27–45 (2011).
3. Paas, F., Tuovinen, J.E., Tabbers, H., Van Gerven, P.W.: Cognitive load measurement as a means to advance cognitive load theory. Educ. Psychol. 38, 63–71 (2003).
4. Riedl, R., Léger, P.-M.: Tools in NeuroIS Research: An Overview. In: Fundamentals of NeuroIS. pp. 47–72. Springer (2016).
5. Ortiz De Guinea, A., Titah, R., Léger, P.-M.: Measure for Measure: A two study multi-trait multi-method investigation of construct validity in IS research. Comput. Hum. Behav. 29, 833–844 (2013).
6. de Guinea, A.O., Titah, R., Léger, P.-M.: Explicit and Implicit Antecedents of Users' Behavioral Beliefs in Information Systems: A Neuropsychological Investigation. J. Manag. Inf. Syst. 30, 179–210 (2014).
7. Xie, B., Salvendy, G.: Prediction of mental workload in single and multiple tasks environments. Int. J. Cogn. Ergon. 4, 213–242 (2000).
8. De Jong, T.: Cognitive load theory, educational research, and instructional design: some food for thought. Instr. Sci. 38, 105–134 (2010).
9. Ryu, K., Myung, R.: Evaluation of mental workload with a combined measure based on physiological indices during a dual task of tracking and mental arithmetic. Int. J. Ind. Ergon. 35, 991–1009 (2005).
10. Wickens, C.D.: Multiple resources and performance prediction. Theor. Issues Ergon. Sci. 3, 159–177 (2002).
11. DeStefano, D., LeFevre, J.-A.: Cognitive load in hypertext reading: A review. Comput. Hum. Behav. 23, 1616–1641 (2007).
12. Mizuno, K., Tanaka, M., Yamaguti, K., Kajimoto, O., Kuratsune, H., Watanabe, Y.: Mental fatigue caused by prolonged cognitive load associated with sympathetic hyperactivity. Behav. Brain Funct. 7, 1 (2011).
13. Gwizdka, J.: Distribution of cognitive load in web search. J. Am. Soc. Inf. Sci. Technol. 61, 2167–2187 (2010).
14. Gopher, D., Donchin, E.: Workload: An examination of the concept. (1986).
15. O'Donnell, R.D., Eggemeier, F.T.: Workload assessment methodology. (1986).
16. Colle, H.A., Reid, G.B.: Double trade-off curves with different cognitive processing combinations: Testing the cancellation axiom of mental workload measurement theory. Hum. Factors J. Hum. Factors Ergon. Soc. 41, 35–50 (1999).
17. Coyne, J.T., Baldwin, C., Cole, A., Sibley, C., Roberts, D.M.: Applying real time physiological measures of cognitive load to improve training. In: Foundations of augmented cognition. Neuroergonomics and operational neuroscience. pp. 469–478. Springer (2009).

18. Garrett, D., Peterson, D.A., Anderson, C.W., Thaut, M.H.: Comparison of linear, nonlinear, and feature selection methods for EEG signal classification. Neural Syst. Rehabil. Eng. IEEE Trans. On. 11, 141–144 (2003).
19. Brouwer, A.-M., Zander, T.O., van Erp, J.B., Korteling, J.E., Bronkhorst, A.W.: Using neurophysiological signals that reflect cognitive or affective state: six recommendations to avoid common pitfalls. Front. Neurosci. 9, (2015).
20. Colle, H.A., Reid, G.B.: Estimating a mental workload redline in a simulated air-to-ground combat mission. Int. J. Aviat. Psychol. 15, 303–319 (2005).
21. Venables, L., Fairclough, S.H.: The influence of performance feedback on goal-setting and mental effort regulation. Motiv. Emot. 33, 63–74 (2009).
22. Aljukhadar, M., Senecal, S., Daoust, C.-E.: Using recommendation agents to cope with information overload. Int. J. Electron. Commer. 17, 41–70 (2012).
23. Desrocher, C., Léger, P.-M., Sénécal, S., Pagé, S.-A., Mirhoseini, S.: The influence of product type, mathematical complexity, and visual attention on the attitude toward the website: The case of online grocery shopping. Presented at the Fourteenth Pre-ICIS SIG-HCI Workshop , Fort Worth, Texas, Dec (2015).
24. Cameron, A.-F.: Juggling multiple conversations with communication technology: Towards a theory of multi-communicating impacts in the workplace. Queen's University (2007).
25. Libenson, M.H.: Practical approach to electroencephalography. Elsevier Health Sciences (2012).
26. DeLeeuw, K.E., Mayer, R.E.: A comparison of three measures of cognitive load: Evidence for separable measures of intrinsic, extraneous, and germane load. J. Educ. Psychol. 100, 223 (2008).

Using Contactless Heart Rate Measurements for Real-time Assessment of Affective States

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Abstract. Heart rate measurements contain valuable information about a person's affective state. There is a wide range of application domains for heart rate-based measures in information systems. To date, heart rate is typically measured using skin contact methods, where users must wear a measuring device. A non-contact and easy to use mobile approach, allowing heart rate measurements without interfering with the users' natural environment, could prove to be a valuable NeuroIS tool. Hence, our two research objectives are (i) to develop an application for mobile devices that allows for non-contact, real-time heart rate measurement and (ii) to evaluate this application in an IS context by benchmarking the results of our approach against established measurements. The proposed algorithm is based on non-contact photoplethysmography and hence takes advantage of slight skin color variations that occurs periodically with the user's pulse.

Keywords: Heart rate • Photoplethysmography • Mobile • NeuroIS • Information systems.

1 Introduction

Affective states are increasingly gaining attention within information systems (IS) research [1]. They provide valuable insights for the evaluation and evolution of IS related domains such as human-computer interaction (HCI) or decision support systems (DSS). Among a range of different tools in NeuroIS research, heart rate (HR) measurements contribute to a deeper understanding of cognitive and affective processes in IS [1, 2]. For example, HR measurements have been used to evaluate the impact of computerized agents in electronic auctions [3], to detect emotions in financial decision making [4] or as neurophysiological correlates for investigating cognitive absorption in enactive training [5]. Hence, there is a great potential for integrating HR measurements as real-time input in various IS domains, e.g., technostress applications [6], e-learning systems [7], and electronic auctions [8].

Recent research investigates increasingly unobtrusive NeuroIS tools for measuring affective states, such as standard mouse devices [9], and aims at designing innovative and useful IT artifacts [10]. While HR data is typically collected using skin contact measurement methods, such as electronic or optical sensors, new algorithms are developed to measure human HR without skin contact by analyzing video recordings [11]. Such techniques fall into the field of non-contact photoplethysmography (PPG) and utilize phenomena such as the periodic variation of humans' skin color to provide reliable methods for measuring HR, without the need to attach sensors to the user's skin. Since a large portion of recent work on non-contact PPG investigates feasibility under lab conditions using previously recorded video, research on mobile real-time applications is scarce.

In this paper, we aim to develop and evaluate an approach for real-time non-contact HR measurements using mobile devices. Our first research objective is the design of an artifact that builds on existing algorithms for non-contact PPG and enables real-time measurements on a mobile device. Our second research objective is the evaluation of the developed artifact in a NeuroIS study by benchmarking it against standard electrocardiogram (ECG) recordings and evaluating limitations and benefits of the developed algorithm for further IS research.

2 Theoretical Background

Recent research shows that remote video recordings of subjects under ambient light contain a rich enough signal to measure vital functions such as HR and respiration rate [12]. Based on the framework of the biological measuring chain [13] we subdivide existing approaches of non-contact PPG for HR measurement into three key steps: (i) signal extraction from a series of images, (ii) filtering of the signal to eliminate noise, and (iii) estimation of the heart beat frequency (i.e. HR). In the following, we review approaches for non-contact PPG and evaluate their appropriateness for IS research with respect to these three steps. They serve as reference and foundation for the proposed real-time, mobile approach to unobtrusively measure HR in IS settings.

Signal extraction. Two main approaches for HR measurement dominate the existing literature on non-contact PPG: HR measurement based on head movement and HR measurement based on color variation. The first approach utilizes periodic motion of the head caused by the opposite reaction of blood being pumped into the head through the aorta. Hence, it requires the head to remain stationary [14–16]. In a mobile approach, it is likely that the user will move. This is why we focus on the second approach, HR measurement based on color variation, which utilizes the subtle change in the skin color of the human face that occurs periodically with the pulse. Invisible to the human eye, this variation can be used to measure the HR using video analysis algorithms [11, 12, 17–20]. The first step is to select the face as the region of interest (ROI). Existing approaches for ROI detection range from manual classification [12, 18] to computationally expensive feature point detection algorithms [20]. For real-time application,

the use of a simple classification algorithm is an appropriate trade-off between complexity and accuracy, permitting an automated ROI detection. Most previous work relies on such algorithms [11, 14, 15, 19, 20].
To eliminate the noise introduced by rigid body movements, the user's face needs to be tracked and the ROI updated. If facial feature points are available, an implementation of an optical flow estimation algorithm can be used [20]. To eliminate non-rigid movements, caused by natural movements in the user's face, areas such as the eyes [20] are usually excluded from the ROI, or the ROI is defined as a rectangle on the user's forehead [18]. The raw signal is then obtained by computing the average value of color channels within the ROI [11, 12, 18, 20]. Whether to use all or rather a subset of color channels from the plethysmographic signal in the subsequent analysis constitutes a trade-off between complexity and information [11, 12, 18].

Filtering. The raw signal can contain high frequency noise (e.g., digital artifacts) and low frequency noise (e.g., illumination changes). Digital filters are usually applied to the raw signal to increase the ratio of signal to noise. The main goal is to emphasize the feasible frequencies for human HR. A moving average filter can be applied to eliminate low frequency noise [15]. Since the HR of a healthy human can be assumed to lie within a certain bandwidth of frequencies, a bandpass filter (e.g., a Butterworth filter) is applied to the signal by many authors [15, 16, 18] to remove the unwanted low- and high frequency noise. [20] use the advanced detrending filter proposed by [21] to remove the long-running trend of the raw signal. In the case of a multidimensional signal, a dimensionality reduction technique is applied to the signals to isolate the desired part of the signal. This can be achieved using the Principal Component Analysis (PCA) [14, 18]. As dimensionality reduction techniques produce multiple components, a way to identify the most periodic component has to be specified, e.g., the component with the highest percentage of spectral power accounted by the first harmonic after a Discrete Fourier Transform (DFT) [16].

Frequency estimation. The HR is extracted from the filtered signal using frequency estimation. Most authors use the DFT [11, 12, 16–18] which converts the filtered signal from the time domain to the frequency domain. The HR can then be estimated from the index of the maximum power response. If the individual beat-by-beat intervals are of interest, a peak detection algorithm should be considered, such as in [22].

3 Approach

According to our first research objective, we developed a non-contact PPG algorithm. The procedure of this algorithm is depicted in Figure 1. The algorithm is designed to run on mobile devices, hence, we strive for high accuracy, given the circumstances of a typical IS setting. Since we assume that the user interacts with an IS and hence, focuses on a screen, we expect a moderate amount of head movement. As real-time computation on a mobile device puts constraints on complexity and time, trade-offs with the amount of information processed are unavoidable. Through parameterization and scalability, we allow for more accurate results in the future as more powerful mobile devices emerge. Additionally, further features such as HR variability, as proposed by [23], could be integrated into the algorithm.

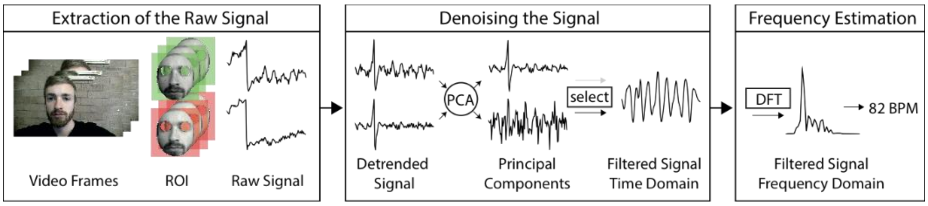

Fig. 1. Overview of our non-contact PPG algorithm approach

For the first step, the ROI is defined. We use the popular Viola-Jones object detector to obtain a bounding box for the face and both eyes of the subject [24]. The ROI comprises an ellipse around the center of the bounding box of the face with 80% of its width and 100% of its height, excluding two circles around the centers of the eyes. This way we are able to capture the subject's face with little noise from background pixels and eye blinking. Faces are re-detected at an adjustable time interval[1] and matched to achieve a quasi-tracking ability. From each frame masked to the ROI, we then spatially pool the colors by choosing the mean values of the red and green channels, similar to the approaches of [11, 18]. We decide to use only the red and green channels as a trade-off between complexity and accuracy following [18]. These values constitute the raw signal.

The second step addresses the removal of noise from the raw signal. In preparation for the PCA, we use the detrending filter proposed by [21] to remove any general trend in the data and isolate rapid leaps in the signal caused by face re-detection. The PCA is then applied to the two-dimensional signal, yielding two principal components. One principal component contains HR information, the other noise due to, e.g., lighting changes or rigid body movements. To identify the principal component that represents the HR signal, we adopt the approach of [16] and choose the one with the more distinct periodicity. Since the signal still contains interfering frequencies, we apply a Butterworth bandpass filter [12, 14–16] with the cut-off frequencies 45 BPM and 240 BPM [16]. In addition, we use a Gaussian smoothing filter to reduce the noise and yield a filtered, one-dimensional signal.

The third step is to estimate the frequency of the heartbeat. For this purpose, we again transform the signal to the frequency domain using a DFT and find the index with the highest spectral power. Using this index, we are able to estimate the HR.

4 Further Research Agenda

Information about users' affective states provide valuable insights for IS research [3, 5, 25]. As HR is an important indicator of emotional arousal, HR measurements are a valuable NeuroIS tool [1, 2]. However, HR measurements are often performed using

[1] We use a default interval of one second for tracking.

ECG or contact PPG, where the user has to wear sensors that require skin contact (i.e., ECG electrodes or finger clip/wristband with optical sensor). To make HR measurements less obtrusive, we addressed the first of our two research objectives in this paper. A non-contact mobile approach for real-time HR measurement is discussed and an algorithm based on recent work on non-contact PPG is developed. Our approach aims at enabling ubiquitous and universal accessibility of HR measurements and could be utilized in the future as real-time system input for both, the evaluation and adaptation of IS. Moreover, recording the data on the user's own smartphone can be considered useful to address privacy protection concerns related to the individual's physiological data. In particular, [6, 26] argued that physiological data of a person should be owned by the respective person. Processing physiological data on their own smartphone enables the user to own this sensitive data and to have direct control over who has access to it.

With respect to the second research objective, we will evaluate this approach by conducting a NeuroIS study similar to the study of [8]. The aim of the planned evaluation study is to benchmark the non-contact real-time measurements of the proposed mobile approach against established ECG HR measurements and evaluate its usefulness for IS research. A study such as [8] would be suitable for the evaluation of the proposed algorithm as it contains elements such as user interaction, social competition, and time pressure, which are likely to be relevant for future studies that include affective information. In this study, the users' affective state is assessed using ECG measurements, which require three skin electrodes on the user's chest. To transfer this lab experiment to the field or to provide users with real-time feedback about their affective states, [8] request a mobile, non-contact solution that extracts information from the acquired data in real-time. Next to the scenario investigated by [8], the proposed NeuroIS tool could be used to provide traders and investors with a direct feedback on their emotional state [27–29] or to support upcoming remedies for technostress [25].

In the evaluation study, we will investigate the accuracy of our proposed PPG-based approach in different scenarios: Resting, low time pressure auction, and high time pressure auction. The study will contain the same elements as the study by [8]. It will be conducted in a lab equipped with a computer terminal for each client. Prior to the auctions, an initial rest period of five minutes will be conducted, during which the participants are asked to relax, so that their physiology can adjust to a resting level. We expect that the PPG-based video image analysis for HR measurements yields the highest accuracy in the resting period section. During the remainder of the experiment, the users' HRs are measured in electronic auctions with low and high levels of time pressure in order to investigate how the accuracy of the non-contact PPG-based approach varies in different settings. As a result of the evaluation study, we will benchmark the measurements based on the proposed application against the measurements by the established ECG technology. We plan to compare the two techniques with respect to subjective as well as objective criteria. Subjective evaluation criteria will depend on the users' perceptions and determine to what extent the users felt distracted by the measurements, objective evaluation criteria will be the correctness of the HR detection. Finally, we will evaluate users' general level of technology acceptance of the proposed measurement approach.

References

1. Riedl, R., Davis, F.D., Hevner, A.R.: Towards a NeuroIS Research Methodology: Intensifying the Discussion on Methods, Tools, and Measurement. J. Assoc. Inf. Syst. 15, i–xxxv (2014).
2. Dimoka, A., Banker, R.D., Benbasat, I., Davis, F.D., Dennis, A.R., Gefen, D., Gupta, A., Ischebeck, A., Kenning, P., Pavlou, P.A., Müller-Putz, G., Riedl, R., Brocke, J. vom, Weber, B.: On the Use of Neurophysiological Tools in IS Research: Developing a Research Agenda for NeuroIS. MIS Q. 36, 679–702 (2012).
3. Teubner, T., Adam, M.T.P., Riordan, R.: The Impact of Computerized Agents on Immediate Emotions, Overall Arousal and Bidding Behavior in Electronic Auctions. J. Assoc. Inf. Syst. 16, 838–879 (2015).
4. Hariharan, A., Adam, M.T.P.: Blended Emotion Detection For Decision Support. IEEE Trans. Human-Machine Syst. 45, 510–517 (2015).
5. Léger, P.-M., Davis, F.D., Cronan, T.P., Perret, J.: Neurophysiological Correlates of Cognitive Absorption in an Enactive Training Context. Comput. Human Behav. 34, 273–283 (2014).
6. Adam, M.T.P., Gimpel, H., Maedche, A., Riedl, R.: Design Blueprint for Stress-sensitive Adaptive Enterprise Systems. Bus. Inf. Syst. Eng.
7. Shen, L., Wang, M., Shen, R.: Affective E-Learning: Using "Emotional" Data to Improve Learning in Pervasive Learning Environment. Educ. Technol. Soc. 12, 176–189 (2009).
8. Adam, M.T.P., Krämer, J., Müller, M.B.: Auction Fever! How Time Pressure and Social Competition Affect Bidders' Arousal and Bids In Retail Auctions. J. Retail. 91, 468–485 (2015).
9. Schaaff, K., Degen, R., Adler, N., Adam, M.T.P.: Measuring Affect Using a Standard Mouse Device. Biomed. Eng. (NY). 57, 761–764 (2012).
10. Vom Brocke, J., Riedl, R., Léger, P.-M.: Application Strategies for Neuroscience in Information Systems Design Science Research. J. Comput. Inf. Syst. 53, 1–13 (2013).
11. Poh, M.-Z., McDuff, D.J., Picard, R.W.: Non-contact, Automated Cardiac Pulse Measurements Using Video Imaging and Blind Source Separation. Opt. Express. 18, 10762–10774 (2010).
12. Verkruysse, W., Svaasand, L.O., Nelson, J.S.: Remote Plethysmographic Imaging Using Ambient Light. Opt. Express. 16, 21434–21445 (2008).
13. Hoffmann, K.-P.: Biosignale Erfassen und Verarbeiten. In: Kramme, R. (ed.) Medizintechnik. pp. 667–688. Springer (2011).
14. Balakrishnan, G., Durand, F., Guttag, J.: Detecting Pulse From Head Motions in Video. In: Proceedings of the 2013 IEEE Computer Society Conference on Computer Vision and Pattern Recognition. pp. 3430–3437 (2013).
15. Irani, R., Nasrollahi, K., Moeslund, T.B.: Improved Pulse Detection From Head Motions Using DCT. In: Proceedings of the 9th International Conference on Computer Vision Theory and Applications. pp. 118–124 (2014).
16. Shan, L., Yu, M.: Video-based Heart Rate Measurement Using Head Motion

Tracking and ICA. In: Proceedings of the 2013 6th International Congress on Image and Signal Processing. pp. 160–164 (2013).
17. Wu, H.-Y., Rubinstein, M., Shih, E., Guttag, J. V, Durand, F., Freeman, W.T.: Eulerian Video Magnification for Revealing Subtle Changes in the World. ACM Trans. Graph. 31, 1–8 (2012).
18. Lewandowska, M., Ruminski, J., Kocejko, T.: Measuring Pulse Rate With a Webcam - A Non-contact Method for Evaluating Cardiac Activity. In: Proceedings of the 2011 Federated Conference on Computer Science and Information Systems (FedCSIS). pp. 405–410 (2011).
19. Kwon, S., Kim, H., Park, K.S.: Validation of Heart Rate Extraction Using Video Imaging on a Built-In Camera System of a Smartphone. In: Proceedings of the 2012 IEEE Annual International Conference of the Engineering in Medicine and Biology Society. pp. 2174–2177 (2012).
20. Li, X., Chen, J., Zhao, G., Pietikäinen, M.: Remote Heart Rate Measurement from Face Videos Under Realistic Situations. In: Proceedings of the 2014 IEEE Computer Society Conference on Computer Vision and Pattern Recognition. pp. 4264–4271 (2014).
21. Tarvainen, M.P., Ranta-Aho, P.O., Karjalainen, P.A.: An Advanced Detrending Method with Application to HRV Analysis. IEEE Trans. Biomed. Eng. 49, 172–175 (2002).
22. Wu, H.-Y.: Eulerian Video Processing and Medical Applications, (2012).
23. Müller, M.B., Adam, M.T.P., Cornforth, D.J., Chiong, R., Krämer, J., Weinhardt, C.: Selecting Physiological Features for Predicting Bidding Behavior in Electronic Auctions. In: Proceedings of the Forty-Ninth Annual Hawaii International Conference on System Sciences (HICSS). pp. 396–405 (2016).
24. Viola, P., Jones, M.: Rapid Object Detection Using a Boosted Cascade of Simple Features. In: Proceedings of the 2001 IEEE Computer Society Conference on Computer Vision and Pattern Recognition. pp. 511–518 (2001).
25. Riedl, R.: On the Biology of Technostress: Literature Review and Research Agenda. ACM SIGMIS Database. 44, 18–55 (2013).
26. Fairclough, S.: Physiological Data Must Remain Confidential. Nature. 505, 263 (2014).
27. Astor, P.J., Adam, M.T.P., Jerčić, P., Schaaff, K., Weinhardt, C.: Integrating Biosignals Into Information Systems: A NeuroIS Tool for Improving Emotion Regulation. J. Manag. Inf. Syst. 30, 247–278 (2013).
28. Lux, E., Hawlitschek, F., Adam, M.T.P., Pfeiffer, J.: Using live biofeedback for decision support: Investigating influences of emotion regulation in financial decision making. In: ECIS 2015 Research-in-Progress Papers. pp. 1–12 (2015).
29. Astor, P.J., Adam, M.T.P., Jähnig, C., Seifert, S.: Measuring Regret: Emotional Aspects of Auction Design. ECIS 2011 Proc. 1129–1140 (2011).

Lifelogging as a viable data source for NeuroIS researchers: A review of neurophysiological data types collected in the lifelogging literature

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Abstract. Based on this review, we argue for the consideration of lifelogging as an additional data source in NeuroIS research. Lifelogging itself is a concept which describes a behavior in which individuals, based on the use of computer technology, track (parts of) their lives, including the quantification of their well-being (e.g., continuous recording of an individual's heart rate via a digital wrist watch). This relatively new form of behavior generates a viable data source for future NeuroIS studies, predominantly for those conducted in field settings. By analyzing how frequently the major types of neurophysiological data have thus far been collected in lifelogging publications, we reveal how much attention different types of neurophysiological data have received in the context of longitudinal field studies. In essence, lifelogging data constitute a viable data base for NeuroIS researchers, one that is readily available and is predicted to grow in the future because an increasing number of people worldwide are tracking their daily lives to a growing extent.

Keywords: Field Studies · Lifelogging · NeuroIS · Self-Tracking

1 Introduction

It has previously been highlighted that there is a lack of NeuroIS studies in the field [1]. While investigations in field settings may imply increased research complexity for several reasons (e.g., intrusion of research into private areas), there is a clear need for the investigation of focal constructs, such as stress, in the daily life of users. In this paper, we highlight the value of data collected by individuals themselves, a behavior which is typically referred to as lifelogging. Thus, lifelogging data constitute a new and readily available data source for NeuroIS researchers.

Lifelogging has the goal of enabling an individual to collect the totality of her/his experiences through the digitization of all cognitive inputs and/or neurophysiological activation [2]. Contemporary lifelogging research has its roots in an early vision of Vannevar Bush [3] who proposed a device which would allow for the capture and storage of all information that an individual would amass over a lifetime. Ongoing developments related to sensor and storage technologies make the realization of such a vision possible (e.g., [2, 4–7].

In the next section, we briefly discuss the concept of lifelogging and highlight previous calls for the use of neurophysiological data in lifelogging research. Afterwards, we review the literature to reveal how much attention different types of neurophysiological data have received in the context of longitudinal lifelogging field studies.

2 Lifelogging

As defined by Dodge and Kitchin [2], a “life-log” is “(…) a form of pervasive computing consisting of a unified digital record of the *totality* of an individual's experiences, captured multimodally through digital sensors and stored permanently as a personal multimedia archive.” (p. 431, italics in original). Hence, lifelogging tools are intended to penetrate an individual’s daily life, collecting data on a longitudinal basis. Though not in the propagated “total” degree, Swan [8] highlighted that such self-tracking behaviors are already an integral part of our life, as many individuals regularly measure something about themselves, in part due to an intrinsic motivation to figure out their inner workings (e.g., related to dietary choices). From a NeuroIS standpoint, health and fitness-related applications, among others, are highly interesting because the type of data collected in these application domains is related to important outcome variables in IS research, such as stress [9, 10] or technostress [11, 12]. Health and fitness-related applications are currently a dominant domain in lifelogging research [13].

Lifelogging could be of interest to an even wider public, and, importantly, often does not involve a significant change in an individual’s daily behavior. In a 2013 survey in the United States, 69% of the participants already reported that they were regularly keeping track of at least one health indicator (e.g., diet or weight) though only 21% used technology to support this endeavor [14]. In a 2014 survey on the same topic, the share of self-trackers in the US public was even higher, with an astounding 91% [15]. Powerful wearable technologies are supporting the increasingly effortless collection of lifelogging data, with IDC estimating that sales in this category will surge from almost 20 million units in 2014 to more than 126 million in 2019, with wrist wear being the dominant type of device in this context (around 80-90% of sales) [16]. In addition, researchers who have been interviewed as part of the more recent survey [15] stated that they are most interested in data specifically related to the well-being of individuals such as vital signs, as well as data on physical activity, mood, and stress.

Importantly, there have been several calls for lifelogging research to more actively focus on the capture of the internal mechanisms of individuals. For example, Nack [17] highlighted that lifelogging has been centered too much around the idea of creating an additional memory, capturing the external context, while widely neglecting the internal context (e.g., affective states and physiological processes). Hence, it has been argued that also unconsciously processed data involved in the physiological functioning of individuals constitute a valuable addition to lifelogging applications (e.g., [2, 18, 19]).

Due to the enormous potential that lifelogging applications hold for NeuroIS research, particularly for investigations conducted in the field, it is important to assess the role of neurophysiological data in lifelogging publications.

3 Neurophysiological data in lifelogging publications

To assess the prevalence of neurophysiological data in lifelogging research, we conducted a literature review based on the following criteria. We used the term "lifelog" in Google Scholar (02/22/2016: 5,050 hits) and selected journal publications as well as publications in scientific periodicals which had accumulated more than five citations thus far[1]. These criteria led to a set of 54 publications, but 16 papers were excluded as they did not offer sufficient information on the types of data involved. Two additional articles were excluded (one only involved paper-based logging of information and the other one involved the collection of personal health information, though only for the use of medical personnel (i.e., a form of monitoring, hence not an application of individual lifelogging).[2]

As lifelogging aims to be all-encompassing, the types of data that are captured can be almost limitless (e.g., [4, 13, 21]). Therefore, we employed an existing categorization scheme introduced by Jacquemard et al. [22] to divide them into four main groups: data on the individual, data on the environment, device-specific data, and third-party data (see Table 1).

The first category is "inward facing", which we describe with *data on the individual*. By far the most popular source of data on the individual in the reviewed publications was motion, measured via accelerometers which can be indicative of physical activity levels, sedentary behaviors, and can even be used to calculate energy expenditures. Additionally, we highlighted studies which utilized the SenseCam, a camera device that has been widely prevalent in lifelogging research. The SenseCam is a wearable camera with a number of integrated sensors that takes images from an individual's point of view every few seconds or even at shorter intervals if the sensors detect a significant change in the environmental setting or changes in an individual's posture (e.g., [23, 24]).

The second category of "outward facing" data includes *data on the environment* which can involve all types of contextual information. Visual lifelogs are by far the most prominent data source in this category, mostly applying the SenseCam for data collection or similar wearable camera devices.

The third category of *device-specific data* includes all kinds of data about information systems and their functioning (e.g., received phone calls, battery status, or used applications).

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[1] A similar criterion has previously been applied in a literature review by Riedl [20].

[2] It has to be noted that we do not claim that the 36 publications which we identified constitute an exhaustive list of available publications.

Table 1. Prevalence of types of data employed in lifelogging publications.

Studies	Citations[3]	Individual	Environment	Device-Specific	Third-Party
Gemmell et al. (2006) [25]	517	X	X	X	X
Choudhury et al (2008) [26]	400	X	X		
Anderson et al. (2007) [27]	167			X	
Berry et al. (2007) [28]	165	(*)	X		
Gyorbiro et al. (2009) [29]	154	X	X	X	
Whittaker et al. (2010) [30]	80		X		
Blum et al. (2006) [31]	78	X	X	X	
Hodges et al. (2011) [24]	68	(*)	X		
Lee et al. (2008) [32]	67	(*)	X		
Ogata et al. (2011) [33]	66	X	X		
Doherty et al. (2011) a [34]	63	(*)	X		
Kelly et al. (2011) [35]	62	(*)	X		
Cho et al. (2007) [36]	59		X	X	X
Whittaker et al. (2008) [37]	50		X		
Jacques et al. (2011) [38]	49	(*)	X		
Doherty et al. (2011) b [39]	45	(*)	X		
Vemuri and Bender (2004) [40]	43		X	X	X
Berry et al. (2009) [41]	43	(*)	X		
Lee et al. (2011) [42]	42	X			
Doherty et al. (2012) [43]	40	(*)	X		
Hwang and Cho (2009) [44]	38		X	X	X
Whittaker et al. (2012) [45]	34	X	X		
Rawassizadeh et al. (2013) [46]	33	X	X	X	
Gurrin et al. (2013) [47]	32	X	X	X	
Abe et al. (2009) [48]	31	X	X		
Byrne et al. (2010) [49]	31	(*)	X		
Browne et al. (2011) [50]	29	(*)	X		
Doherty et al. (2010) [51]	28	(*)	X		X
Pauly-Takacs et al. (2011) [52]	26	(*)	X		
Kikhia et al. (2010) [53]	25		X		
Brindley et al. (2011) [54]	23	X	X		
Ryoo and Bae (2007) [55]	20	X	X		
Ivonin et al. (2013) [19]	20	X	X		
Kalnikaite et al. (2011) [56]	18	X	X		
Ogata et al. (2008) [57]	15		X		
Wang et al. (2012) [58]	12	(*)	X		
(*) = used the SenseCam, but did not use its integrated accelerometer for data collection.					

Finally, in the fourth category of *third-party data* we include data on the individual that has not actually been collected by the individual herself or himself and can be

[3] Assessed via Google Scholar on 02/22/2016.

requested from others (e.g., medical data). In the selected studies, only weather data was collected.

From a NeuroIS standpoint, it is important to note that only three of the reviewed studies (i.e., [19, 54, 55]) included data which is amongst the "common" types of data proposed for NeuroIS (e.g., [59, 60]). Ryoo and Bae [55] presented the concept for a wearable gadget that could also collect cardiovascular activity via ECG and infer stress levels from the gathered signals. Ivonin et al. [19] presented a method to recognize what they labelled "unconscious emotions" from heart signals as an extension for future lifelogging applications. Finally, Brindley et al. [54] used SenseCam to collect visual data, and, in addition, gathered affective data using an ECG monitor on a patient with acquired brain injury. They tested whether data collected during social situations in the field would elicit similar responses in the patient when showing him SenseCam pictures of the same events again in the laboratory.

A potential explanation for the seemingly low popularity of other neurophysiological data in these lifelogging studies is the requirement for lifelogging applications to be effortless [7] (as they should essentially be used throughout the day and ideally capture a whole lifetime), and they therefore need to be particularly unobtrusive. Riedl et al. [61] emphasized that the criterion of intrusiveness is amongst the most important factors in NeuroIS measurement, highlighting that, ideally, neurophysiological tools should allow for a high degree of movement freedom, high degree of natural position, and a low degree of invasiveness. It follows that a number of neurophysiological tools (e.g., fMRI) are not applicable in a lifelogging context.

4 Future directions

Pantelopoulos and Bourbakis [62] and Appelboom et al. [63] listed a number of biological sensors that can be used to gather individual-level data in field settings which not only included cardiovascular activity, but also blood pressure, body and/or skin temperature, respiration rate, oxygen saturation, electro-dermal activity, blood glucose values, muscular activity via electromyogram, or brain activity via electroencephalogram (EEG). Hence, through back-search in our selected publications (see Table 1) we identified a number of inspiring applications which show that lifelogging might actually more strongly embrace neurophysiological signals, which would make this research domain even more interesting from a NeuroIS perspective.

In an early study, Healey and Picard [64] used the startle response, inferred from electro-dermal activity, to create the "StartleCam", a wearable camera which would mainly collect moments that are likely valuable to the individual and hence elicit an affective response. Hori and Aizawa [65] even included a brain-wave analyzer (EEG) in their lifelogging application which may be used to collect alpha waves that would then be informative of an individual's attention levels, which could be used, for example, to more effectively retrieve interesting scenes from a continuous video-log. The array of sensors that could be put on an individual was even further evolved by Matthews et al. [66] who developed a physiological sensor suite (PSS) that could include several modules of physiological sensors including ECG, EEG, electromyogram (muscular activity), and electrooculogram (eye movements).

Aside from being worn by the individual, relevant sensors could also be integrated into the environment, creating ambient applications. For example, Healey and Picard [67] created a set-up which would allow for the collection of physiological data informative of individual stress levels (i.e., cardiovascular activity via ECG, muscular activity via EMG, skin conductance and respiration) inside a car and tested it in an actual field course. Finally, in an organizational setting, McDuff et al. [68] proposed a set-up which would allow employees to track their daily work activities including a WebCam, Microsoft Kinect to capture body movements, microphone, GPS sensor, capture of file activity on the local workstation, and a wrist-worn EDA sensor. Also, Schaaff et al. [69] presented a prototype of a computer mouse equipped with sensors which may detect pressure from individuals interacting with the mouse that could then be used to infer emotional states (e.g., levels of frustration).

Despite the fact that these studies create a more versatile picture of the application of neurophysiological data in lifelogging, they also highlight that a main challenge to the application of such types of data in lifelogging contexts is the number of confounding variables that have to be considered (e.g., [54, 66, 67]), such as noise (e.g., muscle contractions) created from fast movements. This fact has also been pointed out by Appelboom et al. [63] in the context of tele-monitoring, who proposed that the ideal application would have to essentially be tailored to each individual interested in self-tracking, hence requiring a high level of self-interest in the tracking of physiological data by individuals.

In conclusion, while there are applications that show that neurophysiological data can be collected in the field in a longitudinal fashion, the creation of a life-long archive by individuals themselves requires an approach that is mostly driven by the individual herself/himself, though should be supported by researchers interested in the gathered data. Thus, by more actively involving themselves into the development of data collection approaches in the lifelogging domain, NeuroIS researchers could more effectively present their topics (application areas) to individuals interested in self-tracking, and, in addition, create trust in individuals, which has been shown to be an essential critical prerequisite of lifelogging data being shared with interested researchers (e.g., [15]).

References

1. Fischer, T., Riedl, R.: Neurois in Situ: On the Need for Neurois Research in the Field to Study Organizational Phenomena. In: Liang, T.-P., Yen, N.-S. (eds.) Workshop on Information and Neural Decision Sciences, pp. 20–21 (2014)
2. Dodge, M., Kitchin, R.: 'Outlines of a World Coming into Existence': Pervasive Computing and the Ethics of Forgetting. Environment and Planning B: Planning and Design 34, 431–445 (2007)
3. Bush, V.: As We May Think. The Atlantic Monthly, 112–124 (1945)

4. Gurrin, C., Smeaton, A.F., Doherty, A.R.: LifeLogging: Personal Big Data. Foundations and Trends® in Information Retrieval 8, 1–125 (2014)
5. Bell, G.: A Personal Digital Store. Communications of the ACM 44, 86–91 (2001)
6. O'Hara, K., Morris, R., Shadbolt, N., Hitch, G.J., Hall, W., Beagrie, N.: Memories for Life: A Review of the Science and Technology. Journal of the Royal Society, Interface 3, 351–365 (2006)
7. Sellen, A.J., Whittaker, S.: Beyond Total Capture. Communications of the ACM 53, 70 (2010)
8. Swan, M.: The Quantified Self: Fundamental Disruption in Big Data Science and Biological Discovery. Big Data 1, 85–99 (2013)
9. Weiss, M.: Effects of Work Stress and Social Support on Information Systems Managers. MIS Quarterly 7, 29 (1983)
10. Sethi, V., King, R.C., Quick, J.C.: What Causes Stress in Information System Professionals? Communications of the ACM 47, 99–102 (2004)
11. Riedl, R., Kindermann, H., Auinger, A., Javor, A.: Technostress from a Neurobiological Perspective - System Breakdown Increases the Stress Hormone Cortisol in Computer Users. Business & Information Systems Engineering 4, 61–69 (2012)
12. Riedl, R., Kindermann, H., Auinger, A., Javor, A.: Computer Breakdown as a Stress Factor during Task Completion under Time Pressure: Identifying Gender Differences Based on Skin Conductance. Advances in Human-Computer Interaction, 1–8 (2013)
13. Wang, P., Smeaton, A.F.: Using Visual Lifelogs to Automatically Characterize Everyday Activities. Information Sciences 230, 147–161 (2013)
14. Fox, S., Duggan, M.: Tracking for Health (2013)
15. California Institute for Telecommunications and Information Technology: Personal Data for the Public Good. New Opportunities to Enrich Understanding of Individual and Population Health (2014)
16. Worldwide Wearables Market Forecast to Reach 45.7 Million Units Shipped in 2015 and 126.1 Million Units in 2019, According to IDC (2015)
17. Nack, F.: You Must Remember This. IEEE Multimedia 12, 4–7 (2005)
18. Bell, G., Gemmell, J.: A Digital Life. Scientific American 296, 58–65 (2007)
19. Ivonin, L., Chang, H.-M., Chen, W., Rauterberg, M.: Unconscious Emotions: Quantifying and Logging Something We are not Aware of. Personal and Ubiquitous Computing 17, 663–673 (2013)
20. Riedl, R.: On the Biology of Technostress: Literature Review and Research Agenda. DATA BASE for Advances in Information Systems 44, 18–55 (2013)
21. O’Hara, K., Tuffield, M.M., Shadbolt, N.: Lifelogging: Privacy and Empowerment with Memories for Life. Identity in the Information Society 1, 155–172 (2008)
22. Jacquemard, T., Novitzky, P., O'Brolcháin, F., Smeaton, A.F., Gordijn, B.: Challenges and Opportunities of Lifelog Technologies: A Literature Review and Critical Analysis. Science and engineering ethics 20, 379–409 (2014)

23. Hodges, S.E., Williams, L., Berry, E., Izadi, S., Srinivasan, J., Butler, A., Smyth, G., Kapur, N., Wood, K.: SenseCam: A Retrospective Memory Aid. In: Hutchison, D., Kanade, T., Kittler, J., Kleinberg, J.M., Mattern, F., Mitchell, J.C., Naor, M., Nierstrasz, O., Pandu Rangan, C., Steffen, B. et al. (eds.) UbiComp 2006: Ubiquitous Computing, 4206, pp. 177–193. Springer, Berlin, Heidelberg (2006)
24. Hodges, S., Berry, E., Wood, K.: SenseCam: A Wearable Camera that Stimulates and Rehabilitates Autobiographical Memory. Memory 19, 685–696 (2011)
25. Gemmell, J., Bell, G., Lueder, R.: MyLifeBits: A Personal Database for Everything. Communications of the ACM 49, 88–95 (2006)
26. Choudhury, T., Borriello, G., Consolvo, S., Haehnel, D., Harrison, B., Hemingway, B., Hightower, J., Klasnja, P."., Koscher, K., LaMarca, A., et al.: The Mobile Sensing Platform: An Embedded Activity Recognition System. IEEE Pervasive Computing 7, 32–41 (2008)
27. Anderson, I., Maitland, J., Sherwood, S., Barkhuus, L., Chalmers, M., Hall, M., Brown, B., Muller, H.: Shakra: Tracking and Sharing Daily Activity Levels with Unaugmented Mobile Phones. Mobile Networks and Applications 12, 185–199 (2007)
28. Berry, E., Kapur, N., Williams, L., Hodges, S.E., Watson, P., Smyth, G., Srinivasan, J., Smith, R., Wilson, B., Wood, K.: The Use of a Wearable Camera, SenseCam, as a Pictorial Diary to Improve Autobiographical Memory in a Patient with Limbic Encephalitis: A Preliminary Report. Neuropsychological Rehabilitation 17, 582–601 (2007)
29. Gyorbiro, N., Fabian, A., Hományi, G.: An Activity Recognition System for Mobile Phones. Mobile Networks and Applications 14, 82–91 (2009)
30. Whittaker, S., Bergman, O., Clough, P.: Easy on that Trigger Dad: A Study of Long Term Family Photo Retrieval 14, 31–43 (2010)
31. Blum, M., Pentland, A., Troster, G.: InSense: Interest-based Life Logging. IEEE Multimedia 13, 40–48 (2006)
32. Lee, H., Smeaton, A.F., O'Connor, N.E., Jones, G., Blighe, M., Byrne, D., Doherty, A., Gurrin, C.: Constructing a SenseCam Visual Diary as a Media Process. Multimedia Systems 14, 341–349 (2008)
33. Ogata, H., Li, M., Hou, B., Uosaki, N., El-Bishouty, M.M., Yano, Y.: SCROLL: Supporting to Share and Reuse Ubiquitous Learning Log in the Context of Language Learning. Research and Practice in Technology Enhanced Learning 6, 69–82 (2011)
34. Doherty, A.R., Caprani, N., Conaire, C.Ó., Kalnikaite, V., Gurrin, C., Smeaton, A.F., O'Connor, N.E.: Passively Recognising Human Activities through Lifelogging. Computers in Human Behavior 27, 1948–1958 (2011)
35. Kelly, P., Doherty, A.R., Berry, E., Hodges, S.E., Batterham, A.M., Foster, C.: Can We Use Digital Life-log Images to Investigate Active and Sedentary Travel Behaviour? Results from a Pilot Study. The International Journal of Behavioral Nutrition and Physical Activity 8 (2011)
36. Cho, S.-B., Kim, K.-J., Hwang, K.S., Song, I.-J.: AniDiary: Daily Cartoon-style Diary Exploits Bayesian Networks. IEEE Pervasive Computing 6, 66–75 (2007)

37. Whittaker, S., Tucker, S., Swampillai, K., Laban, R.: Design and Evaluation of Systems to Support Interaction Capture and Retrieval. Personal and Ubiquitous Computing 12, 197–221 (2008)
38. Jacques, P.L.S., Conway, M.A., Lowder, M.W., Cabeza, R.: Watching My Mind Unfold versus Yours: An fMRI Study Using a Novel Camera Technology to Examine Neural Differences in Self-projection of Self versus Other Perspectives. Journal of Cognitive Neuroscience 23, 1275–1284 (2011)
39. Doherty, A.R., Moulin, C.J.A., Smeaton, A.F.: Automatically Assisting Human Memory: A SenseCam Browser. Memory 19, 785–795 (2011)
40. Vemuri, S., Bender, W.: Next-Generation Personal Memory Aids. BT Technology Journal 22, 125–138 (2004)
41. Berry, E., Hampshire, A., Rowe, J., Hodges, S., Kapur, N., Watson, P., Browne, G., Smyth, G., Wood, K., Owen, A.M.: The Neural Basis of Effective Memory Therapy in a Patient with Limbic Encephalitis. Journal of Neurology, Neurosurgery, and Psychiatry 80, 1202–1205 (2009)
42. Lee, M.-W., Khan, A.M., Kim, T.-S.: A Single Tri-axial Accelerometer-based Real-time Personal Life Log System Capable of Human Activity Recognition and Exercise Information Generation. Personal and Ubiquitous Computing 15, 887–898 (2011)
43. Doherty, A.R., Pauly-Takacs, K., Caprani, N., Gurrin, C., Moulin, C.J.A., O'Connor, N.E., Smeaton, A.F.: Experiences of Aiding Autobiographical Memory Using the SenseCam. Human-Computer Interaction 27, 151–174 (2012)
44. Hwang, K.-S., Cho, S.-B.: Landmark Detection from Mobile Life Log Using a Modular Bayesian Network Model. Expert Systems with Applications 36, 12065–12076 (2009)
45. Whittaker, S., Kalnikaite, V., Petrelli, D., Sellen, A.J., Villar, N., Bergman, O., Clough, P., Brockmeier, J.: Socio-technical Lifelogging: Deriving Design Principles for a Future Proof Digital Past. Human-Computer Interaction 27, 37–62 (2012)
46. Rawassizadeh, R., Tomitsch, M., Wac, K., Tjoa, A.M.: UbiqLog: A Generic Mobile Phone-based Life-log Framework. Personal and Ubiquitous Computing 17, 621–637 (2013)
47. Gurrin, C., Qiu, Z., Hughes, M., Caprani, N., Doherty, A.R., Hodges, S.E., Smeaton, A.F.: The Smartphone as a Platform for Wearable Cameras in Health Research. American Journal of Preventive Medicine 44, 308–313 (2013)
48. Abe, M., Morinishi, Y., Maeda, A., Aoki, M., Inagaki, H.: A Life Log Collector Integrated with a Remote-controller for Enabling User Centric Services. IEEE Transactions on Consumer Electronics 55, 295–302 (2009)
49. Byrne, D., Doherty, A.R., Snoek, C.G.M., Jones, G.J.F., Smeaton, A.F.: Everyday concept detection in visual lifelogs: Validation, relationships and trends. Multimedia Tools and Applications 49, 119–144 (2010)
50. Browne, G., Berry, E., Kapur, N., Hodges, S., Smyth, G., Watson, P., Wood, K.: SenseCam Improves Memory for Recent Events and Quality of Life in a Patient with Memory Retrieval Difficulties. Memory 19, 713–722 (2011)

51. Doherty, A.R., Smeaton, A.F.: Automatically augmenting lifelog events using pervasively generated content from millions of people. Sensors 10, 1423–1446 (2010)
52. Pauly-Takacs, K., Moulin, C.J.A., Estlin, E.J.: SenseCam as a Rehabilitation Tool in a Child with Anterograde Amnesia 19, 705–712 (2011)
53. Kikhia, B., Hallberg, J., Bengtsson, J.E., Savenstedt, S., Synnes, K.: Building Digital Life Stories for Memory Support. International Journal of Computers in Healthcare 1, 161–176 (2010)
54. Brindley, R., Bateman, A., Gracey, F.: Exploration of Use of SenseCam to Support Autobiographical Memory Retrieval within a Cognitive-behavioural Therapeutic Intervention Following Acquired Brain Injury. Memory 19, 745–757 (2011)
55. Ryoo, D.-w., Bae, C.: Design of the Wearable Gadgets for Life-Log Services Based on UTC. IEEE Transactions on Consumer Electronics 53, 1477–1482 (2007)
56. Kalnikaite, V., Whittaker, S.: A Saunter down Memory Lane: Digital Reflection on Personal Mementos. International Journal of Human-Computer Studies 69, 298–310 (2011)
57. Ogata, H., Misumi, T., Matsuka, T., El-Bishouty, M.M., Yano, Y.: A Framework for Capturing, Sharing and Comparing Learning Experiences in a Ubiquitous Learning Environment. Research and Practice in Technology Enhanced Learning 03, 297–312 (2008)
58. Wang, P., Smeaton, A.F.: Semantics-based Selection of Everyday Concepts in Visual Lifelogging. International Journal of Multimedia Information Retrieval 1, 87–101 (2012)
59. Dimoka, A., Banker, R.D., Benbasat, I., Davis, F.D., Dennis, A.R., Gefen, D., Gupta, A., Ischebeck, A., Kenning, P.H., Pavlou, P.A., et al.: On the Use of Neurophysiological Tools in IS Research: Developing a Research Agenda for NeuroIS. MIS Quarterly 36, 679–702 (2012)
60. Riedl, R., Banker, R.D., Benbasat, I., Davis, F.D., Dennis, A.R., Dimoka, A., Gefen, D., Gupta, A., Ischebeck, A., Kenning, P., et al.: On the Foundations of NeuroIS: Reflections on the Gmunden Retreat 2009. Communications of the Association for Information Systems 27, 243–264 (2010)
61. Riedl, R., Davis, F.D., Hevner, A.R.: Towards a NeuroIS Research Methodology: Intensifying the Discussion on Methods, Tools, and Measurement. Journal of the Association for Information Systems 15, i–xxxv (2014)
62. Pantelopoulos, A., Bourbakis, N.G.: A Survey on Wearable Sensor-Based Systems for Health Monitoring and Prognosis. IEEE Transactions on Systems, Man, and Cybernetics, Part C (Applications and Reviews) 40, 1–12 (2010)
63. Appelboom, G., Camacho, E., Abraham, M.E., Bruce, S.S., Dumont, E.L., Zacharia, B.E., D'Amico, R., Slomian, J., Reginster, J.Y., Bruyère, O., et al.: Smart Wearable Body Sensors for Patient Self-assessment and Monitoring. Archives of public health 72, 28 (2014)

64. Healey, J., Picard, R.W.: StartleCam: A Cybernetic Wearable Camera. In: Proceedings of the Second International Symposium on Wearable Computers, pp. 42–49 (1998)
65. Hori, T., Aizawa, K.: Context-based Video Retrieval System for the Life-log Applications. In: Sebe, N., Lew, M.S., Djeraba, C. (eds.) Proceedings of the 5th ACM SIGMM International Workshop on Multimedia Information Retrieval, pp. 31–38. ACM (2003)
66. Matthews, R., McDonald, N.J., Hervieux, P., Turner, P.J., Steindorf, M.A.: A Wearable Physiological Sensor Suite for Unobtrusive Monitoring of Physiological and Cognitive State. In: Proceedings of 29th Annual IEEE International Conference of the Engineering in Medicine and Biology Society, pp. 5276–5281. IEEE (2007)
67. Healey, J.A., Picard, R.W.: Detecting Stress during Real-world Driving Tasks Using Physiological Sensors. IEEE Transactions on Intelligent Transportation Systems 6, 156–166 (2005)
68. McDuff, D., Karlson, A., Kapoor, A., Roseway, A., Czerwinski, M.: AffectAura: An Intelligent System for Emotional Memory. In: Konstan, J.A., Chi, E.H., Höök, K. (eds.) Proceedings of the ACM SIGCHI Conference on Human Factors in Computing Systems, pp. 849–858 (2012)
69. Schaaff, K., Degen, R., Adler, N., Adam, M.T.P.: Measuring Affect Using a Standard Mouse Device. Biomedical Engineering / Biomedizinische Technik 57 (2012)

A Refined Examination of Worker Age and Stress: Explaining How, and Why, Older Workers Are Especially Techno-Stressed in the Interruption Age

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Abstract. The workforce is aging rapidly, with the number of older workers increasing sharply (older being defined as 60 and over). At the same time, interruptions mediated by modern information technologies are proliferating in organizations. These interruptions include email notifications and instant messages, amongst others, which have been shown to have hazardous consequences for employees in terms of stress. Older workers might be especially affected by these interruptions, implying major problems for this fast-growing user group with regard to their well-being and work performance. The present study tests a research model suggesting that older workers experience more interruption-based technostress than their younger counterparts because of differences in inhibitory control between older and younger adults. In doing so, this study answers recent calls for examining age as a substantive variable in IS research, and it contributes to the literature on technostress by showing how technostress affects different user groups to different extents.

Keywords: Age, Older workers, Inhibition, Stress, Interruptions, Technostress.

1 Introduction

The workforce is aging rapidly; in fact, it is said to be *graying* [1,2,3]. According to the OECD, all of its member countries are experiencing rapid population and workforce aging [2,4,5,6]. As workers age, cognitive and biological changes occur. These changes include, for instance, the reduced ability to operate computer input devices, challenges related to memory decline, and the reduced ability to ignore distracting information in the work environment and remain concentrated on the task at hand [7,8,9]. As a result of these changes, older workers may experience major problems interacting with the ever more modern information technologies at work [10], and they are more at risk of being affected by technological stressors [11].

While the workforce is graying, it also has to deal with an ever-growing number of interruptions mediated by IT, such as a constant stream of instant messages and email notifications. These technology-mediated (T-M) interruptions relentlessly call for workers' attention, causing stress [12,13,14]. The stress linked to IT, termed *tech-*

nostress, can have harmful consequences for workers in the form of elevated levels of stress hormones, causing health problems [15,16,17,18]. Organizations are also affected since workers' performance on IT-based tasks suffers under stress [19].

The negative consequences of T-M interruptions might be especially problematic for a graying workforce [19]. Yet, little guidance exists for software designers on how to design IT with older workers in mind [10]. This research investigates the question of *whether, how, and why age impacts physiological stress in an interruption context*.

The next section presents the Inhibitory Deficit Theory of Cognitive Aging to develop a theoretical model of age and technostress. The model explains that age impacts physiological stress in an interruption context due to older peoples' deficits in inhibiting attentional responses to interrupting stimuli. The third section reports on the model testing and results. The paper ends with an account against age discrimination.

2 Background and Hypotheses

This study answers recent calls for more explicit theorizing as to the role of age in IS research [10]. A research agenda paper suggested that IS scholars theorize "touch points of age" [10], which constitute theoretical points through which age touches on various IS phenomena. This notion suggests that age should be modeled as an indirect cause of IS dependent variables, with an added mediator explaining precisely how and why age matters in a given phenomenon. Examining the role of age in IS phenomena through touch points is important so as to avoid justifying it on stereotypical accounts, as commonly done [10]. In fact, using touch points of age can shed ample light on the theoretical nature of the role of age in IS phenomena. In this study, we examine a touch point of age that might be especially relevant in an interruption context: older peoples' deficits in inhibiting attentional responses to interrupting stimuli.

We ground our study and its touch point of age in the literatures on cognition and cognitive aging [20,21]. These literatures emphasize the importance of working memory to our study context. Working memory is a temporary storage and processing element in the brain that holds the information required for completing an active task [20]. For instance, once a phone number has been looked up, it is held in working memory until it is fully dialed [20]. The capacity of working memory is strictly limited, at times to as few items as one [22]. Given this stringent capacity limitation, interruptions can interfere with task-related information processing when they enter working memory (interrupting stimuli enter working memory when people attend to them) because interruptions draw working memory resources away from the task at hand, leaving fewer resources for task-related information processing. As a result, task-related mental work becomes slow and error-prone (e.g., slow and incorrect dialing of phone numbers or slow reading and writing), leading to stress [20,11].

To avoid stress by ensuring that only relevant information enters working memory, human cognition relies on selective attention [21]. Selective attention refers to the ability to selectively attend to some information sources while ignoring others; it is concerned with the allocation of processing resources. One important mechanism of selective attention is inhibition [23]. The inhibitory mechanism of selective attention is meant to filter out irrelevant stimuli, helping people remain concentrated on a given active task. Effective inhibition involves actively disregarding any distracting stimuli in a task environment. It is goal-directed; people with effective inhibition can deliberately ignore an interrupting stimulus when they have the goal of remaining concentrated and focused on the task at hand. Yet, the effectiveness of attentional inhibition differs greatly across individuals, most importantly as a function of age [8,21].

Research on cognitive aging examines the changes in working memory and selective attention that occur as people age [24]. We draw on the inhibitory deficit theory of cognitive aging, which explains how and why age can impact the active control of the contents of working memory [25].[1] This theory is considered a major theoretical approach to aging [26], and it has received widespread empirical support [27,28,29]. The inhibitory deficit theory holds that attentional inhibition is impaired in older individuals. This impairment is a function of the changes that occur in the frontal lobe, which is the brain component that houses the inhibitory mechanism of selective attention [30,31]. As people age, the frontal lobe's connections with other brain areas deteriorate, and the frontal lobe shrinks. These anatomical declines in the frontal lobe imply corresponding corrosions in the inhibitory mechanism (because the latter is housed in the frontal lobe). The corrosions in the inhibitory mechanism result in the

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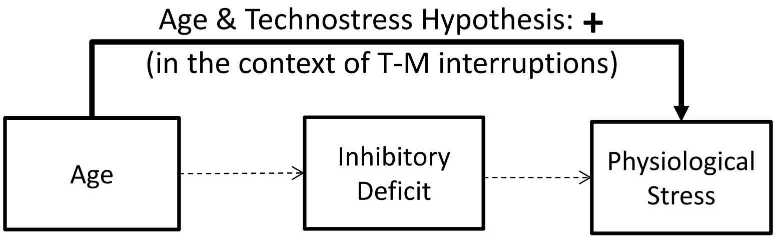
[1] Several theories of age differences in memory and attention have been proposed, including the theories of environmental support, deliberate processing, failure to integrate context, working memory demands, perceptual speed, and failures of inhibition [24]. The theory of environmental support suggests that older adults need more support to engage in effective information processing than younger people, implying that they are less efficient at self-initiated information processing. Similar to the preceding theory, deliberate processing implies that the magnitude of age differences in memory depends on the extent to which a tasks involves deliberate information processing instead of more automatic, habitual processing. Failure to integrate context is a concept that is more specific than the preceding one, suggesting that older adults cannot take advantage of contextual cues because they have problems integrating the memory context with the information they are attempting to remember. The theory of working memory demands is simple, implying, on the basis of the large and reliable age differences that have been found in working memory tasks, that older adults' disadvantages in information processing increase with increasing task demands on working memory. Similarly, the theory of perceptual speed indicates that older adults are slower and process information more slowly than their younger counterparts as a function of the cognitive complexity of a task. Finally, the theory of failures of inhibition posits that older adults are much less able than younger people to actively disregard interrupting stimuli in a task environment [24]. In summary, large age differences in memory and attention can be found to the extent to which a task lacks environmental support, requires deliberate processing, involves integrating to-be-remembered information with context, has large working memory demands, can be influenced by perceptual speed, or requires inhibition of irrelevant information [24]. For this study, we deem the theories of environmental support, deliberate processing, and failure to integrate context as not relevant since our focus is on inhibiting attentional responses to interruptions rather than on support or context. Similarly, while the theories of working memory demands and perceptual speed are applicable to our study context, they are too generic to effectively inform the development of our research hypotheses. The concept of failures of inhibition, however, is directly applicable to our study.

inhibitory deficit that older individuals commonly demonstrate [31]. As a result, in older compared to younger people interrupting stimuli are more likely to gain access to working memory and to interfere with task-related information processing [25].

In sum, we hold that T-M interruptions can be problematic due to the capacity limitation of working memory. Yet, an effective inhibitory mechanism of selective attention can buffer against the negative consequences of T-M interruptions by preventing them from entering working memory in the first place. This mechanism is a protective shield against interruptions. Still, inhibition is impaired in older adults. We hypothesize that, in the context of T-M interruptions, age is positively associated with physiological stress via increases in inhibitory deficits (i.e., inhibitory deficits mediate the positive correlation between age and physiological stress; see Figure 1).



The **line in bold** represents our mediation hypothesis: when encountering T-M interruptions during a task, older people will show higher physiological stress levels than younger people due to an inhibitory deficit (i.e., lower selective attention performance, also understood as less efficient top-down attentional control).

The **dotted lines** represent related direct effects, which are not the focus of our mediation hypothesis but are modeled here only to show what direct effects make up this hypothesis.

Fig. 1. Research Model

Table 1. Construct Definitions

Construct	Definition
Age	Chronologically younger compared to older individuals
Inhibitory Deficit	Extent to which a person has a deficit in deliberately suppressing the mental processing of interrupting stimuli in a task environment such that these stimuli do not gain access to mental resources (e.g., working memory resources); a person's inhibitory deficit reflects lower selective attention performance compared to other people
Physiological Stress	The extent of physiological strain people experience as a result of their interactions with technologies

3 Methodology and Results

To establish the link between age and stress in people who encounter interruptions, we conducted a correlational study. We recruited younger and older participants and invited them to come to a laboratory, in which they performed a working memory task. While the participants were working on the task, interruptions in the form of instant messages appeared on the screen within specific time intervals. Consistent with past research [32], we instructed the participants to ignore the interruptions. Good task performance was incentivized to increase the relevance of the task for the participants and their involvement. Of the 128 participants we recruited, half represented younger users (age<30) and half represented older users (age>60), implying that age was measured as a dichotomous variable with two categories: younger users and older users. This operationalization of age was consistent with research on cognitive aging in general, and with the inhibitory deficit theory in particular [25,27,28,29].

Inhibitory Deficit was evaluated using the Stroop color-word task [33]. This task is the most widely-accepted test for inhibition because it most accurately maps onto the definition of inhibitory deficit [34]. The task requires the participants to ignore certain signals that are attentionally compelling but unwanted; the participants have to suppress their attentional responses to these signals while working on a primary task. This procedure is a direct test of someone's ability to inhibit an attentional response to an irrelevant or intrusive piece of information. More specifically, the Stroop task presents to the participants color names that are printed in non-consistent ink colors. The participants must, then, actively inhibit their attentional responses to the printed names of the colors, while selectively attending only to the ink color in which the words are printed. To illustrate, a participant might have to name the ink color *white* for a word that reads *black* (see Figure 2). Since most people have a natural and strong tendency to read, they must inhibit their attentional response to reading the word *black* in order to correctly name the ink color *white* [34]. This task yields the Stroop effect, which is the difference between participants' response times with congruent and incongruent words. The Stroop task has widespread support in the literature, with test–retest reliabilities ranging from 0.83 to 0.91 [35].[2]

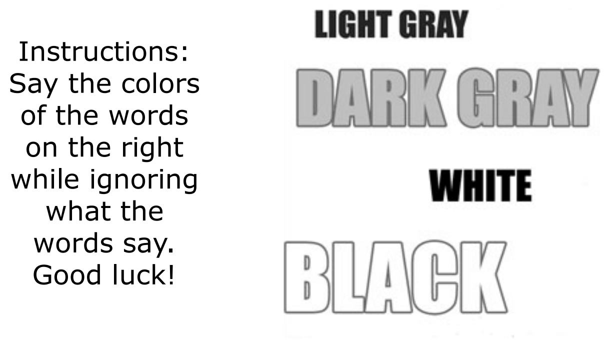


Fig. 2. The Stroop color-word task

[2] It is important to note that the Stroop task is not a stress test but a measure of cognitive functioning. In particular, short Stroop tasks like the one employed here (duration of less than ten minutes) cannot be expected to create stress [36]. Further, the Stroop task employed here was not an experimental treatment but simply a measure of inhibitory deficit (a trait).

Stress was assessed using salivary α-amylase. A-amylase serves as a cutting-edge marker of the sympathetic nervous system component of the psychobiology of stress by reflecting changes in the stress hormone adrenalin (a particularly relevant hormone in the context of computer-related work) [19,37]. A-amylase, in and of itself, is a digestive enzyme produced in the salivary glands. As such, it can be found in saliva in relatively high concentrations. As α-amylase is sensitive to alcohol, food, dairy, and caffeine consumption, we controlled for these factors in our analysis. As is necessary for most physiological research, we also controlled for baseline values of α-amylase.

As regards data analysis, we used Preacher and Hayes' [38] standard SPSS macro for testing indirect effects with a 95% confidence interval and 1,000 bootstrap resamples. The results showed that the hypothesized indirect effect was positive as expected and significant. Since zero was outside the 95% confidence interval, we can conclude with 95% confidence that the indirect effect of age on participants' physiological stress levels via their inhibitory deficits was different from zero (unstandardized coefficient $b = 1.210$, Std. Error = 0.818, $p < 0.05$, LL = 0.058, UL = 3.921).

4 Discussion and Conclusion

Drawing on the inhibitory deficit theory of cognitive aging, this study confirmed that older users experience more physiological stress in today's technology-driven interruption age than younger ones. The study demonstrated that this effect of age is due to differences in users' abilities to ignore T-M interruptions in a computer-mediated task environment and remain focused on the task at hand. Thus, this study makes an important theoretical contribution to IS research, explaining not only *whether* older users experience more technostress in response to T-M interruptions than younger users but also *how and why* they are more bothered by these interruptions (see Figure 3).

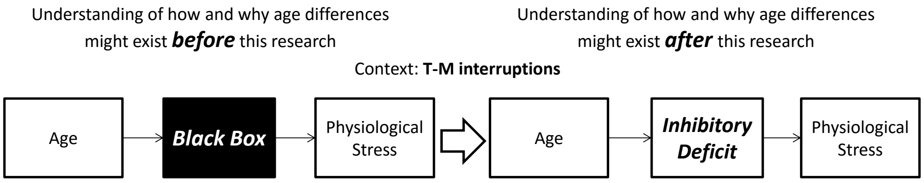


Fig. 3. Theoretical contribution: graying workforces, T-M interruptions, and technostress

Given the facts that the workforce is rapidly growing older across all OECD member countries and that modern technologies such as interruptions are proliferating, our findings are alarming. However, the findings should not be construed as encouraging discrimination against older workers or as encouraging any kind of stereotyping. Instead, they should be considered a means of facilitating the development of intervention strategies that can increase the well-being and productivity of a graying workforce. Ultimately, managerial interventions and technological developments are needed that offset the weaknesses and leverage the strengths of older workers to improve their well-being and increase organizational productivity.

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References

1. OECD: Work-force ageing in OECD countries. In OECD employment outlook 1998. Paris, France: OECD Publishing, pp. 123–151 (1998)
2. OECD: Helping older workers find and retain jobs. In Pensions at a Glance 2011: Retirement-Income Systems in OECD and G20 Countries. Paris, France: OECD Publishing, pp. 67–79 (2011)
3. Pham, S.: The Graying Work Force. The New York Times. Retrieved from http://newoldage.blogs.nytimes.com/2010/11/30/the-graying-workforce/?_php=true&_type=blogs&_r=0 (2010, November 30)
4. OECD: The ageing challenge. In Ageing and the Public Service: Human Resource Challenges. Paris, France: OECD Publishing, pp. 17–28 (2007)
5. OECD: OECD Employment Outlook 2013. Paris, France: OECD Publishing (2013)
6. OECD: Editorial. In International Migration Outlook 2013. Paris, France: OECD Publishing, pp. 9–10 (2013)
7. Charness, N., Holley, P., Feddon, J., Jastrzembski, T.: Light pen use and practice minimize age and hand performance different in pointing tasks, Human Factors, 46(3), 373-384 (2004)
8. Darowski, E. S., Helder, E., Zacks, R. T., Hasher, L., Hambrick, D. Z.: Age-related differences in cognition: The role of distraction control. Neuropsychology, 22(5), 638-644 (2008)
9. Salthouse, T. A., Babcock, R. L.: Decomposing adult age differences in working memory, Developmental Psychology, 27(5), 763-776 (1991)
10. Tams, S., Grover, V., Thatcher, J.: Modern Information Technology in an Old Workforce: Toward a Strategic Research Agenda. Journal of Strategic Information Systems, 23(4), 284–304 (2014)
11. Tams, S.: The Role of Age in Technology-Induced Workplace Stress. Unpublished Doctoral Dissertation, Clemson University, USA (2011)
12. Spira, J. B., Feintuch, J. B.: The cost of not paying attention: How interruptions impact knowledge worker productivity, Basex (2005)
13. Tams, S., Thatcher, J., Grover, V., Pak, R.: Selective Attention as a Protagonist in Contemporary Workplace Stress: Implications for the Interruption Age. Anxiety, Stress, & Coping, 28(6), 663-686 (2015)
14. Tams, S., Thatcher, J., Ahuja, M.: The Impact of Interruptions on Technology Usage: Exploring Interdependencies between Demands from Interruptions, Worker Control, and Role-based Stress. In: Fred D. Davis et al. (eds.) Lecture Notes in information Systems and Organisation: Information Systems and Neuroscience (pp. 19-26), Volume 10, Cham Heidelberg New York Dordrecht London: Springer (2015)
15. Riedl, R., Kindermann, H., Auinger, A., Javor, A.: Technostress from a neurobiological perspective—system breakdown increases the stress hormone cortisol in computer users. Business & Information Systems Engineering, 4(2), 61-69 (2012)
16. Riedl, R.: On the biology of technostress: Literature review and research agenda. The DATA BASE for Advances in Information Systems, 44(1), 18-55 (2013)

17. Riedl, R.: Zum Erkenntnispotenzial der kognitiven Neurowissenschaften für die Wirtschaftsinformatik: Überlegungen anhand exemplarischer Anwendungen. NeuroPsychoEconomics, 4(1), 32-44 (2009)
18. Galluch, P. S., Grover, V., Thatcher, J. B.: Interrupting the Workplace: Examining Stressors in an Information Technology Context. Journal of the Association for Information Systems, 16(1), 1-47 (2015)
19. Tams, S., Hill, K., Ortiz de Guinea, A., Thatcher, J., Grover, V.: NeuroIS – Alternative or Complement to Existing Methods? Illustrating the Holistic Effects of Neuroscience and Self-reported Data in the Context of Technostress Research. Journal of the Association for Information Systems, 15(10), Article 1, 723-753 (2014)
20. Wickens C. D., Lee J., Liu Y. D., Becker, S. G.: Introduction to Human Factors Engineering, NJ: Prentice Hall (2004)
21. Strayer, D. L., Drews, F. A.: Attention. In T. J. Perfect (Ed.) Handbook of applied cognition (2nd ed.), Hoboken, NJ US: John Wiley and Sons Inc, pp. 29-54 (2007)
22. Dumas, J. A., Hartman, M.: Adult age differences in the access and deletion functions of inhibition. Aging, Neuropsychology, and Cognition, 15(3), 330-357 (2008)
23. Houghton, G., Tipper, S. P.: A model of inhibitory mechanisms in selective attention. In T. H. Carr (Ed.) Inhibitory processes in attention, memory, and language. San Diego, CA US: Academic Press, pp. 53-112 (1994)
24. Smith, A. D.: Memory. In T. A. Salthouse (Ed.), Handbook of the psychology of aging (4th ed), San Diego, CA US: Academic Press, pp. 236-250 (1996)
25. Hasher, L., Zacks, R. T.: Working memory, comprehension, and aging: A review and a new view. In G. H. Bower (Ed.) The psychology of learning and motivation: Advances in research and theory, vol. 22. San Diego, CA US: Academic Press, pp. 193-225 (1988)
26. McDowd, J. M., Shaw, R. J.: Attention and aging: A functional perspective. In T. A. Salthouse (Ed.) The handbook of aging and cognition (2nd ed.), Mahwah, NJ US: Lawrence Erlbaum Associates Publishers, pp. 221-292 (2000)
27. Carlson, M. C., Hasher, L., Connelly, S. L. Zacks, R. T.: Aging, distraction, and the benefits of predictable location. Psychology and Aging, 10(3), 427-436 (1995)
28. Hasher, L., Stoltzfus, E. R., Zacks, R. T., Rypma, B.: Age and inhibition. Journal of Experimental Psychology: Learning, Memory, and Cognition, 17(1), 163-169 (1991)
29. Zacks, R., Hasher, L.: Cognitive gerontology and attentional inhibition: A reply to burke and McDowd. Journals of Gerontology Series B: Psychological Sciences and Social Sciences, 52B(6), P274 (1997)
30. Luria, A. R.: The working brain: An introduction to neuropsychology. New York: Basic. (1973)
31. Jurado, M., Rosselli, M.: The elusive nature of executive functions: A review of our current understanding. Neuropsychology Review, 17(3), 213-233 (2007)
32. Theeuwes, J.: Cross-dimensional perceptual selectivity. Perception and Psychophysics, 50(2), 184-193 (1991)
33. Stroop, J. R.: Studies of interference in serial verbal reactions. Journal of Experimental Psychology, 18(6), 643-662 (1935)
34. Shilling, V. M., Chetwynd, A., Rabbitt, P. M. A.: Individual inconsistency across measures of inhibition: An investigation of the construct validity of inhibition in older adults. Neuropsychologia, 40(6), 605 (2002)
35. Spreen, O., Strauss, E.: A compendium of neuropsychological tests. New York: Oxford University Press (1998)

36. Renaud, P., Blondin, J. P.: The stress of Stroop performance: Physiological and emotional responses to color–word interference, task pacing, and pacing speed. International Journal of Psychophysiology, 27(2), 87-97 (1997)
37. Korunka, C., Huemer, K. H., Litschauer, B., Karetta, B., Kafka-Lützow, A.: Working with new technologies: Hormone excretion as an indicator for sustained arousal. A pilot study. Biological Psychology, 42(3), 439-452 (1996)
38. Preacher, K. J., Hayes, A. F.: SPSS and SAS procedures for estimating indirect effects in simple mediation models. Behavior Research Methods, Instruments & Computers, 36(4), 717-731 (2004)

Consumer Grade Brain-Computer Interfaces: an Entry Path into NeuroIS Domains

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Abstract. This research provides a high-level and non-technical insight into the current state of NeuroIS field and a concise overview of consumer grade Brain-Computer interfaces (BCI). Special attention is given to the electroencephalography (EEG) based BCIs. Additionally, a two-dimensional overview with five clusters (Surgical, Clinical, Lab, Office and Plug & play cluster) is proposed as a mean to position NeuroIS tools based on the resource requirements and ease of use. Finally, this research employs a consumer grade BCI (Neurosky Mindwave) in a pilot study and argues for future research on consumer grade BCIs for topics related to information overload.

Keywords: BCI · EEG · Brain-Computer interfaces · Consumerization · Consumer Grade · Plug & Play · Information Overload

1 Introduction

This research understands a brain-computer interface (BCI) as a sum of hardware and software elements of a communications system that permits cerebral activity to control computers or external devices [1, 2, 3]. Consumer grade BCIs represent a special BCI subgroup targeted at consumer market. Consumer BCIs are readily available, easy to install and comfortable to use.

The main goal of this research is to position consumer grade BCIs among other commonly used NeuroIS tools and to test the technical capabilities of a specific consumer grade BCI (EEG based Neurosky Mindwave) in a pilot study. This research proceeds as follows: a brief literature review of thematic, methodological and theoretical advances in NeuroIS field is provided; followed by a two dimensional comparison of brain- computer interfaces with widely used NeuroIS tools and with a set of available consumer grade brain-computer interfaces. This research then presents the results of a pilot study of a consumer grade BCI, namely Neurosky Mindwave, and concludes with suggestions for future consumer grade BCI research.

2 Literature Review

In recent years, the Information Systems (IS) discipline has begun to embrace neural instruments and methods with the intention of complementing existing topics and expanding the understanding of the emergent phenomena. This has led to the creation of a specific branch of IS research, known as Neuro – Information Systems (NeuroIS). NeuroIS has improved the capacity of IS research significantly and a number of research breakthroughs have occurred as a result. NeuroIS has recently been used to answer multiple questions, ranging from understanding technostress [6], information processing biases in virtual teams [7], understanding effects of emotional states on financial trading decisions [8], using measures of risk perception to predict information security behavior [9] and complementing business process modeling tools [10] to name a few.

Thus, it is not surprising that IS scholars started to lay theoretical and methodological grounds on which future research can be built. Reflections on the Gmunden Retreat from 2009 [11] re-defined what NeuroIS is, which tools are relevant for NeuroIS, what IS can learn from neuroscience and what were the current challenges for NeuroIS at that time. A research commentary [12] illustrated the potential of cognitive neuroscience for IS research, especially when it comes to localizing the neural correlates of IS constructs, capturing hidden mental processes and challenging assumptions and enhancing IS theories. Vom Brocke and Liang [13] also contributed to the discipline with a set of guidelines for NeuroIS studies. Those guidelines are designed to help researchers better understand phases typical for NeuroIS research and to guide NeuroIS research through the emerging standards of the discipline. Tams et al. [6] used a technostress study to illustrate the holistic effects that come from using neurosciences and self reported data in tandem. Tams et al. improved our understanding on triangulating different sources of quantitative data by showing the scenario in which different measures can constitute alternatives and/or complements in the prediction of theoretically-related outcomes. Specifically, Tams et al. demonstrated that physiological and psychological measures can actually lead to divergent findings. Furthermore, Gregor et al. [14] developed a nomological network with an overarching view of relationships among emotions and common constructs of interest in NeuroIS research. Finally, Müller-Putz et al. [15] ventured deeply into the foundations, measurements and application of electroencephalography in IS. By publishing their work, Müller-Putz et al. equipped prospective NeuroIS researchers with solid methodological foundations for conducting EEG based research.

3 NeuroIS Tools: Clinical and Consumer Grade Devices

Although NeuroIS continues to prove its value by expanding the knowledge on multiple IS related phenomena; and although sound theoretical and methodological foundations of NeuroIS have been laid out, many IS researchers can still feel reluctant to venture into NeuroIS topics. Some are turned away by significant resources required to conduct a NeuroIS study [16], while others are discouraged by the sheer breadth of non – IS and highly technical knowledge required to successfully conduct a state of the art NeuroIS experiment [15]. In general, NeuroIS research requires researchers to select a proper instrument and equipment that will adequately detect all elicited aspects of researched phenomena, create and maintain all required parameters for the instrument to operate optimally and finally to analyze the readings from the clinical grade neural interfaces [6], [13], [15]. Few IS researchers are properly trained to conduct those studies and some can be deterred by administrative hurdles required to conduct medical-grade research on human subjects. All those factors combined prevent NeuroIS from becoming one of the dominant areas of IS research.

Additionally, a preconceived notion of complexity, ambiguity and dangers [4, 5] of neural instruments may also be one of the culprits for a relatively low proliferation of neural technologies outside the academia. Specifically, it has been known for four decades that the human brain can communicate directly to computers via brain-computer interfaces [1], yet proliferation of those interfaces never happened. Companies like Emotiv, Neurosky and Microsoft are known to work on BCIs [11] and multiple BCIs are even available to a wide consumer audience – but to no avail. Organizations and individual users are still reluctant to include BCIs into their IS infrastructure.

That situation on the ground can perplex IS researchers: Why is it that despite growing research momentum, wide use of BCI did not happen? This research posits that a wide proliferation of BCIs did not happen because the consumer side of NeuroIS is still largely unexplored. In order to explain our reasoning, an overview of the most common NeuroIS tools with accompanying acronyms is presented below (Figure 1). In this figure, the most commonly used NeuroIS tools are classified based on two dimensions: Ease of use (x axis) and Resource requirements (y axis). Ease of use is to be understood as the level of efforts required to use a NeuroIS tool: on the one hand, fMRI requires extensive efforts to set up and run, and considerable efforts to process the outputs of the device. On the other hand, a SCR requires significantly lower amount of efforts, since its use is much more natural to both experimenters and participants. The resource requirements scale should be perceived as the amount of resources (i.e. financial resources, infrastructure, manpower and time) required to successfully use a NeuroIS tools. For the purposes of illustration let us compare a PET and SCR on this scale: a PET requires a clinical level of infrastructure and comes with large upfront and running costs, which dwarfs the resource requirements for SCR[1]. The listed NeuroIS tools in Figure 1 are grouped together into clusters: Clinical cluster represent those devices which are mostly employed in a clinical settings; Lab cluster is positioned between the Clinical and Office cluster since most of the devices that populate this cluster are commonly used in laboratory settings; Office cluster consists of those devices that can be easily used in regular office settings. Surgical cluster is populated with invasive BCIs which tend to stay outside the reach of non medical disciplines [4]. Finally, the Plug & play area depicts all NeuroIS tools which require little to no special conditions and which are ready to use with little or no difficulties.

Clinical, Lab and Office clusters have been extensively used within the NeuroIS literature and the available body of knowledge that originates from those clusters is expanding. However, the Plug & play area represents uncharted waters for NeuroIS and for potential organizational and individual users of BCIs. Noninvasive BCIs are cheap and easy to use, but little is known about their research or usage potentials. Apart from few pioneering studies (e.g. [17, 18]) NeuroIS has not employed consumer grade noninvasive BCI extensively.

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[1]Dimensions of "Resource requirements" and "Ease of use" were adapted from Riedl et al. [11] and Dimoka et al. [16]

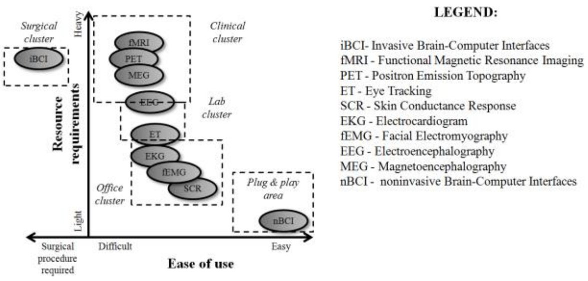

Figure 1. An overview of NeuroIS tools

In order to further explore the Plug and play cluster, which is exclusively populated by noninvasive BCI devices, this research provides a concise and non exhaustive[2] overview of different consumer grade BCIs. According to their respective manufacturers, those devices are able to compliment NeuroIS research and organizational needs at relatively low resource demands, while being easy to use. One device from this cluster (Emotiv Epoc) was used in the previously mentioned studies [17, 18].

Table 1. A non-exhaustive overview of consumer grade BCIs

Name	EEG	EMG	ECG	EOG	Manufacturer	Released
Open BCI Ganglion (R&D)	X	X	X		OpenBCI	Summer 2016
iFocusBand	X				iFocus	October 2014
Emotiv Epoc	X				EmotivSystems	December 2009
Emotiv Insight	X				EmotivSystems	August 2015
Muse	X				InteraXon	April 2014
Aurora Headband				X	Iwinks	July 2015
MindSet	X				NeuroSky	March 2007
MyndPlay	X				MyndPlay	December 2011
MelonHeadband	X				Melon	Nov 2014
XWave Sonic	X				PLX Devices	February 2013
MindWave	X				NeuroSky	March 2011
Mindflex	X				NeuroSky (Mattel)	December 2009
Neural Impulse Actuator		X			OCZ	April 2008

EEG - Electroencephalogram, EMG - Electromyograph,
ECG - Electrocardiogram , EOG – Electrooculograp; adapted from [20]

4 Mindwave Neurosky Pilot Experiment

With that in mind and with an intention to test a consumer level BCI, a pilot study with one of the devices from Table 1 was conducted. The selected device, Neurosky Mindwave headband (highlighted in Table 1; headband in the following text), was used to gather data from a group of 12 test subjects[3]. Neuro Experimenter software v3.28 was used to access the API of the headband and to record EEG based BCI data [21]. All participating subjects of this pilot study were healthy PhD students at a medium-sized private university in the southern part of the United States. All subjects were right handed, and between the ages of 27 and 35. Two participants were female.

[2] Please consult [19] for a more exhaustive overview of wearable EEG sensors and interfaces.
[3] All recorded data is available for download from here: https://goo.gl/bOcDGt

All recordings were gathered in a standard office environment, while subjects were working on light office tasks that required them to use a computer (e.g. checking email inbox, browsing the Internet and arranging files etc.).

According to software manufacturer's specification, the headband and the software used in this pilot study records brainwave readings every 500ms, via a "cluster sensor" positioned on the participant's forehead and targeted at the prefrontal cortex (PFC). PFC is known to be the executive center of the human brain [12], [16], [23], where decision actions (e.g. calculations) are performed. Descriptive statistics of the gathered data are presented in Table 2. In depth analysis of gathered data (e.g. outliers and ERPs) was omitted as a result of technical constraints of this venue of publication.

Table 2. Descriptive statistics of the data collected from Neurosky Mindwave headband

EEG Bands	N	Minimum	Maximum	Mean	Std. Deviation	Variance
Delta	16217	.50	98.64	47.48	27.12	735.28
Theta	16217	.17	81.30	21.22	13.01	169.25
Alpha1	16217	.01	71.88	7.45	6.93	47.98
Alpha2	16217	.04	58.22	6.60	6.12	37.45
Beta1	16217	.06	45.21	6.08	5.57	31.02
Beta2	16217	.04	46.94	5.58	5.09	25.89
Gamma1	16217	.02	37.46	3.26	3.25	10.54
Gamma2	16217	.01	30.44	2.33	2.41	5.83

Number of observations – 16217, blinks – 2551, Data points with an error/missing recording - 394

To sum, this pilot study continues a research direction set by previous studies [23], [24] by demonstrating that a consumer grade BCI recording only one single channel (Fp1) can be used to collect EEG signals in a regular office environment. Naturally, spatial and temporal resolutions of the recordings are not identical to the standards that are generally employed in clinical level EEG studies [15], [23] – instead of dozens of simple sensors, the headband used in this pilot study has only one "clustered sensor"; and instead of the recommended 200ms temporal resolution this system (i.e. the headband and the employed software) is capable of recording only 500 ms intervals. However, according to criteria presented in Kübler et al. 2001 [1], the headband used in this study fits all the requirements for a BCI because it successfully detected the electrophysiological activity of the user's brain, recorded the signals at 97.62% accuracy (which is above the proposed 70% threshold) and bypassed most of the stated limitations.

5 Future Research: How Can Consumer Grade BCIs Help in Detecting Information Overload?"

This pilot study paves the way for using BCIs in NeuroIS to better understand and detects one of the growing technostress phenomena known as information overload (IO). IO can be defined from two perspectives. On the one side, IO occurs on organizational levels when the amount of input to a system exceeds its processing capacity [25] and thus causes negative or unwanted effects for the organization and its employees. On the other side, individuals experience IO as state in which a vast amount of information is readily available, almost instantaneously, without mechanisms to check the validity of the content and the potential risk of misinformation [32, 33]. In short, IO can be understood as a state in which there is just too much information to cope with [34]. Thus, it follows that IO puts a tremendous strain on individuals and on individual cognitive performances – especially on the short term memory function of the human brain and on the executive center of the brain located in the pre frontal lobe [12], [42, 43, 44].

In previous research, a set of clinical grade instruments, such as FMR scan or EEG were used to further the understanding of the human brain [12]. However, IO would be difficult to induce in a clinical/lab environment and potential results might be unusable for practitioners (i.e. it is not practical to regularly monitor employees with a FMR scanner). Therefore, if we are to detect and treat IO in real-life organizational scenarios a more mobile and wearable technology is needed. Consumer grade BCIs seems to fit into that description perfectly. With that in mind, a study with two different consumer grade neural interfaces (Epoc Emotiv and Neurosky Mindwave) and real-life tasks is proposed. Ideally, the author hopes that the mentioned study will provide additional insights about detection and prevention of IO overload through the use of BCIs.

6 Contributions

This research brings multiple contributions. Firstly, it provides a concise and non-technical insight into the current state of the NeuroIS field. Secondly, a classification of commonly used neural tools is proposed (Figure 1). In it, different neural tools are grouped on the basis of resource intensity and ease of use, which lead to the creation of five distinct clusters. Thirdly, special attention has been given to one cluster which was not used as widely as the other clusters and an overview of different noninvasive consumer grade BCIs has been provided (Table 1). Fourthly, this research conducted a preliminary study in which a BCI system is used to collect and process brainwave readings. And finally, this research proposed a potential study in which BCIs can be used to detect, prevent and better understand a rampant problem of information overload.

7 Conclusion

In conclusion, this research might on the one hand encourage the novice and prospective IS researchers to consider joining the growing NeuroIS community by adding neural tools from the resource light and easy to use Plug & play cluster into their research instrumentarium. That should allow novice researchers to circumvent seemingly overwhelming technical and medical demands imposed by the sheer complexity of neuroscience. On the other hand, I hope that this research might point the attention of NeuroIS veterans and practitioners to a promising and partially neglected phenomenon of noninvasive consumer grade BCIs.

Bibliography

1. Kübler, A., Kotchoubey, B., Kaiser, J., Wolpaw, J.R., Birbaumer, N.: Brain-computer communication: Unlocking the locked in. Psychol. Bull. 127, 358–375 (2001).
2. Lotte, F., Congedo, M., Lécuyer, A., Lamarche, F., Arnaldi, B.: A review of classification algorithms for EEG-based brain-computer interfaces. J. Neural Eng. 4, R1–R13 (2007).
3. Nicolas-Alonso, L.F., Gomez-Gil, J.: Brain Computer Interfaces, a Review. Sensors. 12, 1211–1279 (2012).
4. Engber, D.: The Neurologist Who Hacked His Brain—And Almost Lost His Mind, http://www.wired.com/2016/01/phil-kennedy-mind-control-computer/.
5. Piore, A.: To Study the Brain, a Doctor Puts Himself Under the Knife, https://www.technologyreview.com/s/543246/to-study-the-brain-a-doctor-puts-himself-under-the-knife/.
6. Tams, S., Hill, K., Ortiz de Guinea, A., Thatcher, J., Grover, V.: NeuroIS—alternative or complement to existing methods? illustrating the holistic effects of neuroscience and self-reported data in the context of technostress research. J Assoc Inf Syst. 15, 723–753 (2014).
7. Minas, R.K., Potter, R.F., Dennis, A.R., Bartelt, V., Bae, S.: Putting on the Thinking Cap: Using NeuroIS to Understand Information Processing Biases in Virtual Teams. J. Manag. Inf. Syst. 30, 49–82 (2014).
8. Astor, P.J., Adam, M.T.P., Jerčić, P., Schaaff, K., Weinhardt, C.: Integrating Biosignals into Information Systems: A NeuroIS Tool for Improving Emotion Regulation. J. Manag. Inf. Syst. 30, 247–278 (2013).
9. Vance, A., Anderson, B.B., Kirwan, C.B., Eargle, D.: Using measures of risk perception to predict information security behavior: insights from electroencephalography (EEG). J. Assoc. Inf. Syst. 15, 679 (2014).
10. Shitkova, M., Holler, J., Jörg, B., Léger, P.-M.: The Potentials of Neuroscience Methods for Business Process Modeling Tools.
11. Riedl, R., Banker, R., Benbasat, I., Davis, F., Dennis, A., Dimoka, A., Gefen, D., Gupta, A., Ischebeck, A., Kenning, P., Müller-Putz, G., Pavlou, P., Straub, D., Brocke, J. vom, Weber, B.: On the Foundations of NeuroIS: Reflections on the Gmunden Retreat 2009. Commun. Assoc. Inf. Syst. 27, (2010).
12. Dimoka, A., Pavlou, P.A., Davis, F.D.: Research Commentary—NeuroIS: The Potential of Cognitive Neuroscience for Information Systems Research. Inf. Syst. Res. 22, 687–702 (2010).
13. Brocke, J. vom, Liang, T.-P.: Guidelines for Neuroscience Studies in Information Systems Research. J. Manag. Inf. Syst. 30, 211–234 (2014).
14. Gregor, S., Lin, A.C.H., Gedeon, T., Riaz, A., Zhu, D.: Neuroscience and a Nomological Network for the Understanding and Assessment of Emotions in Information Systems Research. J. Manag. Inf. Syst. 30, 13–48 (2014).
15. Müller-Putz, G., Riedl, R., C, S.: Electroencephalography (EEG) as a Research Tool in the Information Systems Discipline: Foundations, Measurement, and Applications. Commun. Assoc. Inf. Syst. 37, (2015).

16. Dimoka, A., Banker, R.D., Benbasat, I., Davis, F.D., Dennis, A.R., Gefen, D., Gupta, A., Ischebeck, A., Kenning, P., Pavlou, P.A., Müller-Putz, G., Riedl, R., Brocke, V., Jan, Weber, B.: On the Use of Neurophysiological Tools in IS Research: Developing a Research Agenda for NeuroIS. MIS Q. 36, 679–702 (2012).
17. Kuan, K.K.Y., Zhong, Y., Chau, P.Y.K.: Informational and Normative Social Influence in Group-Buying: Evidence from Self-Reported and EEG Data. J. Manag. Inf. Syst. 30, 151–178 (2014).
18. Minas, R.K., Potter, R.F., Dennis, A.R., Bartelt, V., Bae, S.: Putting on the Thinking Cap: Using NeuroIS to Understand Information Processing Biases in Virtual Teams. J. Manag. Inf. Syst. 30, 49–82 (2014).
19. Balanou, E., van Gils, M., Vanhala, T.: State-of-the-art of wearable EEG for personalized health applications. Stud. Health Technol. Inform. 189, 119–124 (2013).
20. Comparison of consumer brain–computer interfaces, https://en.wikipedia.org/w/index.php?title=Comparison_of_consumer_brain%E2%80%93computer_interfaces&oldid=700981088, (2016).
21. NeuroExperimenter, http://store.neurosky.com/products/neuroexperimenter.
22. Sitnikova, E., Hramov, A.E., Koronovsky, A.A., van Luijtelaar, G.: Sleep spindles and spike–wave discharges in EEG: Their generic features, similarities and distinctions disclosed with Fourier transform and continuous wavelet analysis. J. Neurosci. Methods. 180, 304–316 (2009).
23. Das, R., Chatterjee, D., Das, D., Sinharay, A., Sinha, A.: Cognitive load measurement - A methodology to compare low cost commercial EEG devices. In: 2014 International Conference on Advances in Computing, Communications and Informatics (ICACCI. pp. 1188–1194 (2014).
24. Grierson, M., Kiefer, C.: Better Brain Interfacing for the Masses: Progress in Event-related Potential Detection Using Commercial Brain Computer Interfaces. In: CHI ’11 Extended Abstracts on Human Factors in Computing Systems. pp. 1681–1686. ACM, New York, NY, USA (2011).
25. Speier, C., Valacich, J.S., Vessey, I.: The Influence of Task Interruption on Individual Decision Making: An Information Overload Perspective. Decis. Sci. 30, 337–360 (1999).
26. Oldroyd, J.B., Morris, S.S.: Catching Falling Stars: A Human Resource Response to Social Capital’s Detrimental Effect of Information Overload on Star Employees. Acad. Manage. Rev. 37, 396–418 (2012).
27. Oracle: The Coming Revolution in Revenue Management. (2012).
28. McKinsey: Big data: The next frontier for innovation, competition, and productivity | McKinsey & Company, http://www.mckinsey.com/insights/business_technology/big_data_the_next_frontier_for_innovation.
29. Lau, R., ter Hofstede, A.H.M., Bruza, P.D.: Nonmonotonic reasoning for adaptive information filtering. In: Computer Science Conference, 2001. ACSC 2001. Proceedings. 24th Australasian. pp. 109–116 (2001).

30. Turetken, O., Sharda, R.: Visualization Support for Managing Information Overload in the Web Environment. ICIS 2001 Proc. (2001).
31. Dale, R., Lei, L., De Vries, H., Gardiner, M., Tilbrook, M.: Summarising company announcements. In: Proceedings of 2005 IEEE International Conference on Natural Language Processing and Knowledge Engineering, 2005. IEEE NLP-KE '05. pp. 651–656 (2005).
32. Flew, T.: New Media: An Introduction. OUP Australia and New Zealand, South Melbourne, Vic. (2007).
33. Graham, G.: The Internet: A Philosophical Inquiry. Routledge, London ; New York (1999).
34. Sobotta, N.: A Systematic Literature Review on the Relation of Information Technology and Information Overload. Presented at the Hawaii International Conference on System Sciences (2016).
35. Bawden, D., Robinson, L.: The dark side of information: overload, anxiety and other paradoxes and pathologies. J. Inf. Sci. 35, 180–191 (2009).
36. Hu, T., Zhang, P., Zhang, X., Dai, H.: Gender Differences in Internet Use: A Logistic Regression Analysis. AMCIS 2009 Proc. (2009).
37. Rutsky, R.L.: Techno-Cultural Interaction and the Fear of Information. Style. 33, 267–281 (1999).
38. Radicati Group: Email Statistics Report, 2015-2019. (2015).
39. GWI: GWI Social: Q3 2015 | Flagship Report Series, http://insight.globalwebindex.net/social.
40. Edison Research, Triton Digital: The Infinite Dial 2015. (2015).
41. Pew Research Center: How Americans Use Text Messaging, http://www.pewinternet.org/2011/09/19/how-americans-use-text-messaging/, (2011).
42. Dimoka, A.: How to conduct a functional magnetic resonance (fMRI) study in social science research. MIS Q. 36, 811–840 (2012).
43. Fuster, J.M., Bodner, M., Kroger, J.K.: Cross-modal and cross-temporal association in neurons of frontal cortex. Nature. 405, 347+ (2000).
44. Goldman-Rakic, P.S., Cools, A.R., Srivastava, K.: The Prefrontal Landscape: Implications of Functional Architecture for Understanding Human Mentation and the Central Executive [and Discussion]. Philos. Trans. Biol. Sci. 351, 1445–1453 (1996).

MEASURING THE POPULARITY OF RESEARCH IN NEUROSCIENCE INFORMATION SYSTEMS (NeuroIS)*

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Abstract. Research in Neuroscience Information Systems aka NeuroIS has gained considerable momentum in the past decade. The purpose of this study is to examine thelandscape of research conducted in the emerging discipline of NeuroISin order to track the progression in the field. Our analysis is based on a systematic review of 59 papers published in high impact conferences and journalsover the past five years (2011 to 2015 inclusive). It offers a bird eye view to the upcoming researchers who intend to pursueNeuroIS research.

Keywords: NeuroIS ·Literature Review· Topical Analysis

1 INTRODUCTION

Information Systems (IS) studies typically rely on traditional methods of research, primarily surveys and experimental setups. Recently researchers have drawn interest in Cognitive Neuroscience (CN) discipline to address the very issue of decision making (DM) in IS users. The issue of DM has been researched not only in neurosciences but also in IS [1, 2].Many popular IS theories like theory of reasoned action, Technology Acceptance Model, and effort accuracy framework have been used for the said purpose [3]. The IS community is witnessing a growing interest in applying theories, methods and tools in neuroscience to inform IS research [4]. For this purpose, the use of brain imaging tools in the CN discipline has provided a useful model.

This phenomenon has given rise to the sub-field of "NeuroIS", which has consistently gained momentum over the past 5 years. This sub-field employs brain imaging tools to inform its research. Most popular tools in this regard are fMRI, EKG, and EEG. These CN tools can be used along with traditional IS tools like questionnaires, and surveys. Also, triangulation of measures provides greater validation across measures thus enhancing the ecological validity of IS studies [4]. A dedicated conference on the subfield of "NeuroIS" has been held on an annual basis for the last several years. It is called the "Gmunden Retreat on NeuroIS".

Given this interest in this sub-field of IS, the goal of this work is to review and report publications in this area over the past five years. This essentially establishes a strong

* The term NeuroIS was first coined by Angelika Dimoka in the year 2007.

ground for its acceptability in the IS research community and provides a consolidated overview of avenues where aspiring NeuroIS researchers can aim to publish their work.

Table 1. Considered publication outlets

Name	Type
European Journal of Information Systems (EJIS)	journal
Information Systems Journal (ISJ)	journal
Information Systems Research (ISR)	journal
Journal of Association of Information Systems (JAIS)	journal
Journal of Information Technology (JIT)	journal
Journal of Management Information Systems (JMIS)	journal
Journal of Strategic Information Systems (JSIS)	journal
Management Information Systems Quarterly (MISQ)	journal
International Conference on Information Systems (ICIS)	proceedings
Americas Conference on Information Systems (AMCIS)	proceedings
Pacific Asia Conference on Information Systems (PACIS)	proceedings
Mediterranean Conference on Information Systems (MCIS)	proceedings
European Conference on Information Systems (ECIS)	proceedings

The rest of the paper is organized as follows. In the next section we discuss the research methodology and study overview. Results are mentioned in section 4. Section 5 presents a discussion of the results and we conclude with a summary in the end.

2 STUDY OVERVIEW

This paper systematically reviews NeuroIS literature being published in high-impact journals (AIS approved "Basket of 8") and conferences (recognized by AIS) during the period from 2011 to 2015. Table 1 list sources used to elicit the articles and their type i.e. journal or conference proceedings. The general purpose of this paper is to integrate the literature published in this domain in the past 5 years. What enhances the rigor of this study is its validity and reliability [5]. Validity in the sense that the databases covered are the registered ones provided on the Association for Information System's (AIS) website. Moreover, the keywords pertain to the exact terms being used in such studies, whereas, the period covered is essentially the one that contains a lower bound from where the specific studies actually started to get published [6] and until the last year. It is reliable in the sense that it documents the above mentioned procedure in enough detail to be replicated. Accordingly, the directorial research question of this study is, *"Whether the NeuroIS subfield of IS has proven its mark as an established and viable area of research in Information Systems?"* The keyword used for this search was "neurois". The reason behind using this keyword only is the idea that if there is an article that necessarily reports this particular kind of research then it will, somewhere in the article, mention this term. This is so because "neurois" is the only keyword that defines work in this field. Moreover, the keywords were searched on the AIS website (http://aisel.aisnet.org/), therefore the results included the related terms (for e.g. fMRI, HCI, trust, brain, emotions etc.) automatically.

Table 2Frequency of NeuroIS publications in AIS recognized Journals and Conferences

Year	2011	2012	2013	2014	2015	others	Comments
EJIS	0	0	0	0	0	1	2015 online publication; yet to be included in forthcoming issues
ISJ	0	0	0	0	1	-	only 1 editorial in 2015
ISR	1	0	0	0	0	-	-
JAIS	0	1	0	4	1	-	2014 special issue
JIT	0	0	0	0	0	-	-
JMIS	0	0	1	7	1	-	-
JSIS	0	0	0	0	0	-	-
MISQ	0	2	1	0	0	-	-
Total	1	3	2	11	3	1	Total = 21
ICIS	3	4	3	5	4	-	-
AMCIS	1	0	0	2	7	-	-
PACIS	0	0	0	1	0	-	-
MCIS	0	1	0	0	0	-	-
ECIS	1	1	1	1	3	-	-
Total	5	6	4	9	14	-	Total = 38
Total	6	9	6	20	17	-	21+38 = 59

3 RESULTS

Table 3. Summary of NeuroIS topics and respective methods and tools

Topic	Methods & Tools
EJIS	
Forthcoming	
User's perception and response to security messages. [C] 5	ET
ISJ	
2015	
editorial on exploring potential of NeuroIS in IS research [O] 2	Editorial
ISR	
2011	
exploring potential of NeuroIS in IS research [O] 3	Research commentary
JAIS	
2012	
historical analysis [O] 3	Review paper

Topic	Methods & Tools
2014	
NeuroIS research methodology [O] 3	Methodological paper
NeuroIS for reporting Technostress studies [O] 5	Methodological paper
Users' disregard of security warnings [D] 4	EEG
Application of EFRP to IS research [O] 7	Methodological paper
2015	
Emotions(arousal) and bidding behavior in e-auctions [E] 3	SCR, HR
JMIS	
2013	
Emotional regulation in financial decisions [E, D] 5	Conceptual and design paper
2014	
understanding and assessment of emotions in IS [E] 5	EEG
understanding information processing bias [D] 5	EEG
Trust and mentalizing in human-avatar interaction [S] 5	fMRI
User engagement in online gaming [C] 4	EEG
Social influence in group-buying [S] 3	EEG
Perceived ease of use and usefulness [C] 3	EEG
Guidelines for neuroscience studies in IS research [O] 2	Conceptual paper
2015	
Role of self-control in information security violations [C] 3	EEG
MISQ	
2012	
Use of Neurophysiological tools for developing NeuroIS agenda [O] 14	Conceptual and review paper
how to conduct fMRI studies [O] 1	Methodological paper
2013	
IS research and behavioral economics [O] 1	Editorial
ICIS	
2011	
Emotions (arousal) in electronic markets (auctions) [E] 4	Methodological paper
Online payment method choice [D] 2	ET
Trust and mentalizing in human-avatar interaction [S] 5	fMRI
2012	
Consumer's online cognitive scripts [C] 4	EEG
Connectivity analysis in NeuroIS research [O] 5	Methodological paper
Emotions in online financial markets wih humans and agents [E] 3	Conceptual paper
Startle reflex modulation for measuring affective information processing [O] 2	Methodological paper
2013	
Effect of arousal and valence on mouse interaction [E] 3	Mouse cursor movement
Trust in social networking sites [S] 5	fMRI
Experience and pressure in IS usage behavior [C] 7	ET
2014	
Habituation to security warnings [C] 5	fMRI
Consumer impulsiveness in online trust evaluations [S] 4	fMRI
Variance and process types of IS research [O] 2	Methodological paper
Emotions and Aesthetics in ICT Usage [E] 2	EEG

Topic	Methods & Tools
Content familiarity in web design [E] 1	Conceptual paper
2015	
Emotion, attention and behavioral control [E] 2	fEMG
System un-related emotions in adoption of IS [E] 2	Conceptual paper
Information avoidance behavior [C] 1	Conceptual paper
Enterprise Resource Planning (ERP) system design [E] 1	Conceptual/behavioral paper
AMCIS	
2011	
NeuroIS research methods [O] 2	Review paper
2014	
Cognition in online shopping markets [C] 2	fMRI
Trust [S] 3	Conceptual paper
2015	
Privacy paradox [D] 2	Conceptual paper
Technostress and users' response to security warnings [E] 5	Hormone (saliv. str.)
Human-Information-Processor Model View of e-Government [C] 2	Conceptual paper
Organizational Memory [C] 2	Conceptual paper
TAM [C] 1	Conceptual paper
Technostress [O] 1	Methodological paper
Visual aesthetics [E] 4	GSC, fEMG, behavioral paper
PACIS	
2014	
Metacognition in e-commerce [C] 2	fMRI
MCIS	
2012	
Technology acceptance [C] 5	EEG
ECIS	
2011	
Emotions (regret) in electronic markets (auctions) [E] 4	SC
2012	
Human centered design [O] 3	Methodological paper
2013	
Emotional regulation in financial decisions [E, D] 3	Conceptual and design paper
2014	
Emotions (arousal) in electronic markets (auctions) [E] 3	EEG, SCR, HR
2015	
Emotional regulation in financial decisions [O] 4	Methodological paper
Job Strain Information System Service (JSISS) [E] 9	Conceptual and design paper
Technostress [O] 3	Methodological and design paper

Acronyms: *EEG* electroencephlography, *ET* eye-tracking, *fEMG* facial electromyography, *fMRI* functional magnetic resonance imaging, *GSC* Galvanic skin conductance, *HR* heart rate, *saliv. str.*salivary stress, *SC* skin conductance, *SCR* skin conductance response. Code for paper categorization: [C]=cognitive processes, [E]=emotional processes, [S]=social processes and [D]=decision-making processes. The code is followed by the number of authors of the papers.

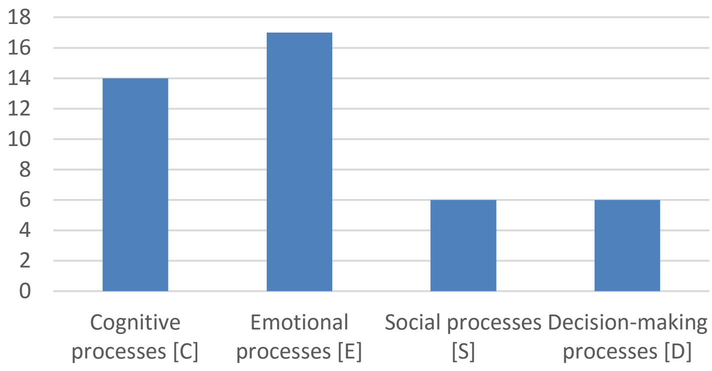

Fig. 1. NeuroIS paper categorization (N=59) [8-66] (y-axis: absolute no. of papers)

Table 4[1]. Methods and tools used in NeuroIS research

Method/Tool	2011	2012	2013	2014	2015	Forth-coming	Abso-lute	Relative (%)
Papers (total)	6	9	6	20	17	1	59	100
EEG	0	2	0	8	1	0	11	19
fMRI	1	0	1	5	0	0	7	12
SC, SCR, GSC	1	0	0	1	2	0	4	7
ET	1	0	1	0	0	1	3	5
HR	0	0	0	1	1	0	2	3
fEMG	0	0	0	0	2	0	2	3
Mouse cursor move-ment	0	0	1	0	0	0	1	2
Hormones (saliva)	0	0	0	0	1	0	1	2
Miscellaneous	3	7	3	6	12	0	31	53

[1] Miscellaneous includes both conceptual and methodological paper and the “Relative” category doesn’t sum up to 100 as some papers have adopted more than one method and tool.

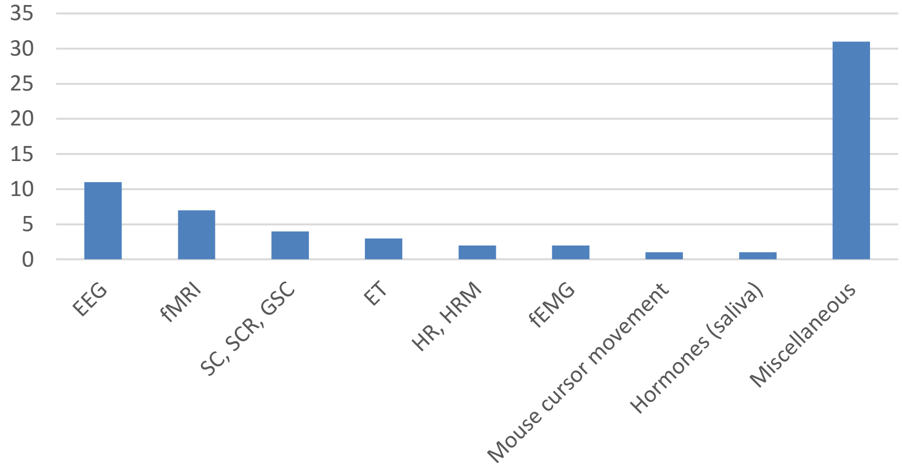

Fig. 2. Popularity of methods & tools in NeuroIS research

4 DISCUSSION

The articles published in above mentioned outlets pertain to significant contributions in different kinds of mental processes like cognitive, emotion, social and decision processes [6, 7]. An insight into the overall progression is presented drawing on the results mentioned above, and following implications could be made from each.

A consistent rise has been observed in the past 5 years in the number of publications within the NeuroIS domain as far as the emotional processes and their impact is concerned. Whereas cognitive processes stands second in place. A dearth has been observed in exploration of social and decision-making processes and hence calls for more contributions in these areas. On the basis of our sample (N=59) [8-66], Fig.2 shows that EEG is the most popular tool in NeuroIS studies followed by fMRI and eye-tracking.

5 CONCLUSION

This literature review indicated the importance of neurosciences in IS and how the field of NeuroIS is establishing its grounds in the research community thereby proving its mark as an established field of research. It reported the progress in the field in terms of number of publications pertaining to cognitive, emotional, social and decision-making processes, thereby gauging its popularity. As an outlook, we see that more NeuroIS contributions are needed in order to report studies involving social and decision-making processes. Thus, the IS community can benefit from incorporating the neurosciences tools, methods and techniques by exploiting its inter-disciplinary nature.

References

1. Hubert, M., Linzmajer, M., & Hubert, M. Neural Evidence of Uncertainty and Risk Processing Networks in Information System Research: A Multilevel-Mediation Approach.
2. Xu, Q., &Riedl, R. (2011). Understanding Online Payment Method Choice: An Eye-Tracking Study.
3. Jannach, D., Zanker, M., Ge, M., &Gröning, M. (2012). Recommender systems in computer science and information systems–a landscape of research (pp. 76-87). Springer Berlin Heidelberg.
4. Dimoka, A., Banker, R. D., Benbasat, I., Davis, F. D., Dennis, A. R., Gefen, D., ...& Müller-Putz, G. (2010). On the use of neurophysiological tools in IS research: Developing a research agenda for NeuroIS.
5. VomBrocke, J., Simons, A., Niehaves, B., Riemer, K., Plattfaut, R., &Cleven, A. (2009, June). Reconstructing the giant: On the importance of rigour in documenting the literature search process. In ECIS (Vol. 9, pp. 2206-2217).
6. Riedl, R., & Léger, P. M. (2016). Fundamentals of NeuroIS: Information Systems and the Brain. Springer.
7. Dimoka, A., Pavlou, P. A., & Davis, F. D. (2011). Research commentary-NeuroIS: the potential of cognitive neuroscience for information systems research. Information Systems Research, 22(4), 687-702.
8. Anderson, B. B., Vance, A., Kirwan, B., &Eargle, D. How Users Perceive and Respond to Security Messages: A NeuroIS Research Agenda and Empirical Study.
9. Dimoka, A., Pavlou, P. A., & Davis, F. D. (2011). Research commentary-NeuroIS: the potential of cognitive neuroscience for information systems research. *Information Systems Research*, *22*(4), 687-702.
10. Belanger, F., & Xu, H. (2015). The role of information systems research in shaping the future of information privacy. *Information Systems Journal*,*25*(6), 573-578.
11. Davern, M., Shaft, T., &Te'eni, D. (2012). Cognition matters: Enduring questions in cognitive IS research. *Journal of the Association for Information Systems*, *13*(4), 273.
12. Riedl, René; Davis, Fred D.; and Hevner, Alan R. (2014) "Towards a NeuroIS Research Methodology: Intensifying the Discussion on Methods, Tools, and Measurement," Journal of the Association for Information Systems: Vol. 15: Iss. 10, Article 4.
13. Tams, Stefan; Hill, Kevin; Ortiz de Guinea, Ana; Thatcher, Jason; and Grover, Varun (2014) "NeuroIS—Alternative or Complement to Existing Methods? Illustrating the Holistic Effects of Neuroscience and Self-Reported Data in the Context of Technostress Research," *Journal of the Association for Information Systems*: Vol. 15: Iss. 10, Article 1.
14. Vance, Anthony; Anderson, Bonnie Brinton; Kirwan, C. Brock; and Eargle, David (2014) "Using Measures of Risk Perception to Predict Information Security Behavior: Insights from Electroencephalography (EEG)," *Journal of the Association for Information Systems*: Vol. 15: Iss. 10, Article 2.
15. Léger, Pierre-Majorique; Sénecal, Sylvain; Courtemanche, François; Ortiz de Guinea, Ana; Titah, Ryad; Fredette, Marc; and Labonte-LeMoyne, Élise (2014) "Precision is in the Eye of the Beholder: Application of Eye Fixation-Related Potentials to Information Systems Research,"*Journal of the Association for Information Systems*: Vol. 15: Iss. 10, Article 3.
16. Teubner, Timm; Adam, Marc; and Riordan, Ryan (2015) "The Impact of Computerized Agents on Immediate Emotions, Overall Arousal and Bidding Behavior in Electronic Auctions," *Journal of the Association for Information Systems*: Vol. 16: Iss. 10, Article 2.

17. Astor, P. J., Adam, M. T., Jerčić, P., Schaaff, K., &Weinhardt, C. (2013). Integrating biosignals into information systems: A NeuroIS tool for improving emotion regulation. *Journal of Management Information Systems*, *30*(3), 247-278.
18. Gregor, S., Lin, A. C., Gedeon, T., Riaz, A., & Zhu, D. (2014). Neuroscience and a nomological network for the understanding and assessment of emotions in information systems research. *Journal of Management Information Systems*, *30*(4), 13-48.
19. Minas, R. K., Potter, R. F., Dennis, A. R., Bartelt, V., & Bae, S. (2014). Putting on the thinking cap: using NeuroIS to understand information processing biases in virtual teams. *Journal of Management Information Systems*, *30*(4), 49-82.
20. Riedl, R., Mohr, P. N., Kenning, P. H., Davis, F. D., &Heekeren, H. R. (2014). Trusting humans and avatars: A brain imaging study based on evolution theory. *Journal of Management Information Systems*, *30*(4), 83-114.
21. Li, M., Jiang, Q., Tan, C. H., & Wei, K. K. (2014). Enhancing user-game engagement through software gaming elements. *Journal of Management Information Systems*, *30*(4), 115-150.
22. Kuan, K. K., Zhong, Y., & Chau, P. Y. (2014). Informational and normative social influence in group-buying: Evidence from self-reported and EEG data.*Journal of Management Information Systems*, *30*(4), 151-178.
23. de Guinea, A. O., Titah, R., & Léger, P. M. (2014). Explicit and implicit antecedents of users' behavioral beliefs in information systems: A neuropsychological investigation. *Journal of Management Information Systems*, *30*(4), 179-210.
24. vomBrocke, J., & Liang, T. P. (2014). Guidelines for neuroscience studies in information systems research. *Journal of Management Information Systems*,*30*(4), 211-234.
25. Hu, Q., West, R., &Smarandescu, L. (2015). The role of self-control in information security violations: insights from a cognitive neuroscience perspective. *Journal of Management Information Systems*, *31*(4), 6-48.
26. Dimoka, Angelika; Banker, Rajiv; Benbasat, Izak; Davis, Fred; Dennis, Alan R.; Gefen, D; Gupta, Alok; Ischebeck, Anja; Kenning, Peter; Pavlou, Paul A.; Muller-Putz, Gernot; Riedl, René; vomBrocke, Jan; and Weber, Bernd. 2012. "On the Use of Neurophysiological Tools in IS Research: Developing a Research Agenda for NeuroIS," *MIS Quarterly*, (36: 3) pp.679-702.
27. Dimoka, Angelika. 2012. "How to Conduct a Functional Magnetic Resonance (fMRI) Study in Social Science Research," *MIS Quarterly*, (36: 3) pp.811-840.
28. Goes, P. B. (2013). Editor's comments: information systems research and behavioral economics. *MIS quarterly*, *37*(3), iii-viii.
29. Marc Adam, Matthias Gamer, Jan Krämer, and Christof Weinhardt, "Measuring Emotions in Electronic Markets" (December 5, 2011). *ICIS 2011 Proceedings.* Paper 1.
30. Qing Xu and René Riedl, "Understanding Online Payment Method Choice: An Eye-tracking Study" (December 6, 2011). *ICIS 2011 Proceedings.* Paper 18.
31. René Riedl, Peter Mohr, Peter Kenning, Fred Davis, and HaukeHeekeren, "Trusting Humans and Avatars: Behavioral and Neural Evidence" (December 6, 2011). *ICIS 2011 Proceedings.* Paper 7.
32. Senecal, S., Léger, P. M., Fredette, M., &Riedl, R. (2012). Consumers' Online Cognitive Scripts: A Neurophysiological Approach.
33. Hubert, M.; Linzmajer, M.; Riedl, R.; Kenning, P.; Hubert, M.: Introducing Connectivity Analysis to NeuroIS Research. Proceedings of the 33rd International Conference on Information Systems (ICIS), 2012.

34. Zhang, S.; Adam, M.; Weinhardt, C.: Humans versus Agents: Competition in Financial Markets of the 21st Century. Proceedings of the 33rd International Conference on Information Systems (ICIS), 2012. [Research-in-progress paper]
35. Koller, M., and Walla, P. (2012). Measuring Affective Information Processing in Information Systems and Consumer Research – Introducing Startle Reflex Modulation. ICIS Proceedings, Breakthrough ideas, full paper in conference proceedings, Orlando 2012.
36. Grimes, G. M., Jenkins, J. L., &Valacich, J. S. (2013). Exploring the Effect of Arousal and Valence on Mouse Interaction. International Conference on Information Systems. Milan, Italy. December 15-18, 2013.
37. Kopton, I., Sommer, J., Winkelmann, A., Riedl, R., & Kenning, P. (2013). Users' Trust Building Processes During Their Initial Connecting Behavior in Social Networks: Behavioral and Neural Evidence. International Conference on Information Systems. Milan, Italy. December 15-18, 2013.
38. Eckhardt, A., Maier, C., Hsieh, J. J., Chuk, T., Chan, A., Hsiao, J., &Buettner, R. (2013). Objective measures of IS usage behavior under conditions of experience and pressure using eye fixation data. International Conference on Information Systems. Milan, Italy. December 15-18, 2013.
39. Anderson, B., Vance, T., Kirwan, B., Eargle, D., & Howard, S. (2014). Users aren't (necessarily) lazy: using neurois to explain habituation to security warnings.
40. Hubert, M., Hubert, M., Riedl, R., & Kenning, P. (2014). How Consumer Impulsiveness Moderates Online Trustworthiness Evaluations: Neurophysiological Insights.
41. Ortiz de Guinea, A., & Webster, J. (2014). Overcoming Variance and Process Distinctions in Information Systems Research.
42. Bhandari, U., & Chang, K. (2014). Role of emotions and aesthetics in ICT usage for underserved communities: a NeuroIS investigation.
43. Gleasure, R.. (2014). Using Distractor Images in Web Design to Increase Content Familiarity: A NeuroIS Perspective. *ICIS*.
44. Neben, T., & Schneider, C. (2015). Ad Intrusiveness, Loss of Control, and Stress: A Psychophysiological Study.
45. Zhang, S., &Milic, N. (2015). Carryover Effects of System-Unrelated Emotions on Adoption of Information Systems.
46. Neben, T. (2015). A Model of Defensive Information Avoidance in Information Systems Use.
47. Darban, M. (2015). Emotional Foundations of Individual's Perception: The Case of Technology Radicalness.
48. Riedl, Rene and Rueckel, David, "Historical Development of Research Methods in the Information Systems Discipline" (2011). AMCIS 2011 Proceedings - All Submissions. Paper 28.
49. Zhang, Z., &Teo, H. H. (2014). An fMRI-based NeuroIS Research on Metacognition in the Context of E-commerce.
50. Walterbusch, M., Gräuler, M., &Teuteberg, F. (2014). How trust is defined: A qualitative and quantitative analysis of scientific literature.
51. Mohammed, Z., & Tejay, G. (2015). The Role of Cognitive Disposition in Deconstructing the Privacy Paradox: A Neuroscience Study.
52. Anderson, B., Eargle, D., Jenkins, J., Kirwan, B., & Vance, T. (2015). The Impact of Technostress on Users' Responses to Security Warnings: A NeuroIS Study.
53. Ndicu, M., &Vedadi, A. (2015). The Human-Information-Processor Model View of e-Government.

54. Barros, V., & Ramos, I. (2015). Using Social Media as Organizational Memory consolidation mechanism according to Attention Based View Theory.
55. Buettner, R. (2015). Towards a New Personal Information Technology Acceptance Model: Conceptualization and Empirical Evidence from a Bring Your Own Device Dataset.
56. Tams, S. (2015). Challenges in Technostress Research: Guiding Future Work.
57. Bhandari, U., CHUA, W. Y., Chang, K., &Neben, T. (2015). Follow Your Heart or Mind? Measuring Neurophysiological Responses and Subjective Judgments for Visual Aesthetics.
58. Zhang, Z., &Teo, H. H. (2014). Metacognition in B2C E-Commerce: a Cognitive Neuroscience Perspective. In *PACIS* (p. 285).
59. Moridis, Christos N.; Terzis, Vasileios; Economides, Anastasios A.; Karlovasitou, Anna; and Karabatakis, Vasileios E., "Integrating TAM with EEG Frontal Asymmetry" (2012). *MCIS 2012 Proceedings.* Paper 5.
60. Astor, Philipp; Adam, Marc; Jähnig, Caroline; and Seifert, Stefan, "MEASURING REGRET: EMOTIONAL ASPECTS OF AUCTION DESIGN" (2011). ECIS 2011 Proceedings. Paper 88.
61. Gleasure, Rob; Feller, Joseph; and O'Flaherty, Brian, "HUMAN-CENTRED DESIGN: EXISTING APPROACHES AND A FUTURE RESEARCH AGENDA" (2012). *ECIS 2012 Proceedings.* Paper 105.
62. Gimpel, Henner; Adam, Marc Thomas Philipp; and Teubner, Timm, "Emotion Regulation In Management: Harnessing The Potential Of Neurois Tools" (2013). *ECIS 2013 Research in Progress.* Paper 3.
63. Hariharan, A., Adam, M. T. P., &Fuong, K. (2014). Towards understanding the interplay of cognitive demand and arousal in auction bidding.
64. Lux, Ewa; Hawlitschek, Florian; Adam, Marc T.P.; and Pfeiffer, Jella, "Using Live Biofeedback for Decision Support: Investigating Influences of Emotion Regulation in Financial Decision Making" (2015). *ECIS 2015 Research-in-Progress Papers.* Paper 50.
65. Kowatsch, Tobias; Wahle, Fabian; Filler, Andreas; Kehr, Flavius; Volland, Dirk; Haug, Severin; Jenny, Gregor J.; Bauer, Georg; and Fleisch, Elgar, "Towards Short-term Detection of Job Strain in Knowledge Workers with a Minimal-invasive Information System Service: Theoretical Foundation and Experimental Design" (2015). *ECIS 2015 Research-in-Progress Papers.* Paper 24.
66. Gimpel, Henner; Regal, Christian; and Schmidt, Marco, "myStress: Unobtrusive Smartphone-Based Stress Detection" (2015). ECIS 2015 Research-in-Progress Papers. Paper 16.