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).

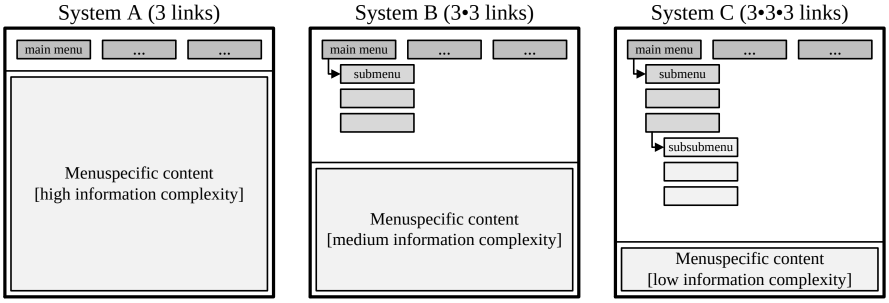

Fig. 1. Conceptualized website complexity (System A: low menu complexity – high information complexity; System B: average menu complexity – average information complexity; System C: high menu complexity – low information complexity)

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]).

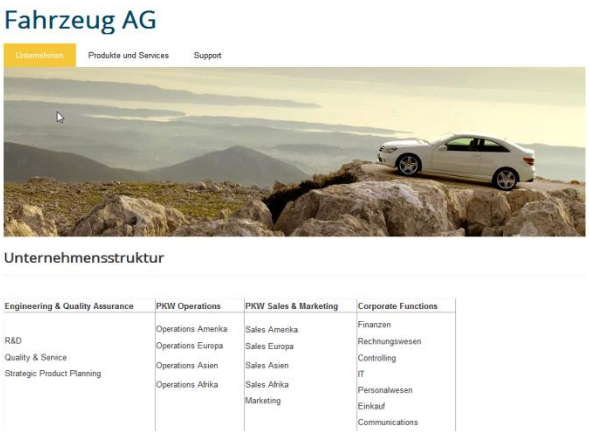

Fig. 2. Exemplary screenshot of system A.

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].

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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)