Analyzing Mental Workload States on the Basis of the Pupillary Hippus

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In the following I report promising results from an initial experiment which applies a novel method for determining a user's mental workload state based on the analysis of pupillary Hippus using eye-tracking technology during human-computer interaction (HCI).

Since evaluating mental workload states from observing the human pupillary is an objective, cheap, non-invasive and efficient method, well established in psychology (Beatty 1982), eye-tracking based pupillometry is a promising method in information systems (IS) research, especially in NeuroIS and HCI (e.g., Buettner et al. 2013). However, prior research has mainly focused on static parts of the pupillary response (e.g., diameter values) and very little research exists that considers the phasic parts (frequency domain) of the pupillary responses.

The so-called pupillary Hippus which describes the oscillating pupillary unrest was completely neglected in IS research, although it is known that this Hippus is strongly linked to a user's mental workload (Bouma and Baghuis 1971).

Initially Stark et al. (1958) observed the continuous small fluctuations of the human pupil around a frequency of 0.2 Hz (so-called pupillary Hippus, tremor, or unrest). Campbell et al. (1959) figured out that the relevant bandwidth of this pupillary Hippus is at 0-0.5 Hz. Bouma and Baghuis (1971) then found that mental activity causes an immediate disappearance of Hippus.

This sparked my interest in investigating whether mental workload states could be derived from pupillary Hippus data. To this end I conducted a within-participant designed experiment which was divided into two sequential parts – first a workload intensive part, subsequently followed by a relaxation part. For the workload intensive part I employed a well-documented task from psychology. According to (Beatty 1982), participants memorize and reproduce numbers from three to nine digits. For the relaxation part I applied the progressive relation technique (cf. Scheufele 2000) using music and imagery from the 2006 football World Cup.

To capture the pupil of both participants' eyes I used the binocular double EyegazeEdgeTM System eye-tracker (2*60Hz, 19'' LCD monitor (86 dpi) at 1280x1024).

Analysing the frequency domain of the pupillary signal I hypothesized lower power values of the Hippus relevant bandwidth of 0-0.5 Hz at the workload state (memorizing/reproducing task) compared to the relaxation state (relaxing music and imagery task) [H1]. Twelve volunteers (six females) aged from 21 to 38 (M=26.2, SD=4.1) participated. As a result, the power values of the Hippus relevant band shown in Table 1 were significantly greater at the relaxation state compared to the workload state (t-tests, $p_{left\ eye} < .001$, $p_{right\ eye} < 0.001$) which confirms hypothesis [H1].

Table 1. Results of the Hippus relevant bandwidth (0-0.5 Hz) power (in system units) calculated with MathWorks MATLAB R2014a. Values are normally distributed (Kolmogorov-Smirnov test).

	Workload state		Relaxation state	
	left eye	right eye	left eye	right eye
S1	2.8669	2.9290	3.8536	4.2951
S2	2.5441	2.4849	2.9652	3.0227
S3	1.7474	1.6923	2.3802	2.3098
S4	1.7622	1.8512	1.8720	1.9319
S5	2.1604	2.2474	2.4181	2.5383
S6	2.4541	2.6285	3.1042	3.3289
S7	1.7078	1.7017	2.2433	2.1504
S8	2.6755	2.8433	3.8871	4.1757
S9	3.1024	3.3780	3.7967	4.2462
S10	1.9641	2.1149	2.9128	3.0162
S11	1.6441	1.6580	2.5925	2.6767
S12	2.0034	1.7508	2.4776	2.1748
M	2.2194	2.2733	2,8753	2,9889

Since I found large effect sizes (Cohens $d_{left\ eye} = 1.109$, $d_{right\ eye} = 0.980$; effect size $r_{left\ eye} = 0.485$, $r_{right\ eye} = 0.440$), the method of analysing the pupillary Hippus in order to identify the users mental workload is very promising for IS research, especially in NeuroIS and HCI, but needs further experimental evaluation.

References

- Beatty, J. 1982. Task-Evoked Pupillary Responses, Processing Load, and the Structure of Processing Resources. Psychol Bull, 91(2), pp. 276-292.
- Buettner, R., Daxenberger, B., Eckhardt, A., and Maier, C. 2013. "Cognitive Workload Induced by Information Systems: Introducing an Objective Way of Measuring based on Pupillary Diameter Responses," *Pre-ICIS HCI/MIS 2013 Proceedings*, Paper 20.
- Bouma, H., and Baghuis, L. 1971. "Hippus of the pupil: Periods of slow oscillations of unknown origin," *Vision Research* 11(11), pp. 1345-1351.
- Campbell, F., Robson, J., and Westheimer, G. 1959. "Fluctuations of accommodation under steady viewing conditions," *J Physiol* 145(3), pp. 579-594.
- Scheufele, P. 2000. "Effects of Progressive Relaxation and Classical Music on Measurements of Attention, Relaxation, and Stress Responses," *J of Behavioral Medicine* 23(2), pp. 207-228.
- Stark, L., Campbell, F., and Atwood, J. 1958. "Pupil unrest: an example of noise in a biological servomechanism," *Nature* 182(4639), pp. 857-858.