Assessing Cognitive Workload on Printed and Electronic Media using Eye-Tracker and EDA Wristband

Iuliia Brishtel[1,2], **Shoya Ishimaru**[1,2,3], **Olivier Augereau**[3], **Koichi Kise**[3], **Andreas Dengel**[1,2,3]
[1]German Research Center for Artificial Intelligence (DFKI);
[2]TU Kaiserslautern; [3]Osaka Prefecture University
{Iuliia.Brishtel, Shoya.Ishimaru, Andreas.Dengel}@dfki.de, {augereau@m., kise@}cs.osakafu-u.ac.jp

ABSTRACT
With the expansion of e-learning platforms, we receive a great opportunity to learn and study just using an electronic device. In this paper, we measured the differences in information processing on screen and paper with 18 participants using an eye-tracker and an EDA wristband. Our findings show that the media type has a significant influence on cognitive workload and understandability of the content. The results of this work are of vital importance for the design of new intelligent user interfaces and reveal the necessity to take mental processes of users more into account.

ACM Classification Keywords
H.5 Information interfaces and presentation (e.g., HCI): H.5.2 User Interfaces, Interaction Style.

Author Keywords
E-learning; Eye-Tracking; Reading; Information Processing; Electrodermal Activity; Cognitive Workload; User-Interface

INTRODUCTION
According to "Global Market Insights", market for Learning Management System (LMS) grows every year at a 5% and is expected to reach approximately 240 billion USD by 2030. In order to provide appropriate means for knowledge transfer, the design of e-learning environment plays the key role in educational process [1].

Previous research, however, pointed out considerable differences in information processing on paper and electronic surfaces [2]. The results show significant advantages for learning processes on printed media compared to its digital counterpart. For the user interface design this fact means a demand for deeper understanding of more specific cognitive processes by users on the one hand and implementation of new evaluation methods to access these processes on the other hand.

IUI'18 Companion March 7–11, 2018, Tokyo, Japan

ACM ISBN 978-1-4503-5571-1/18/03. . . $15.00
DOI: https://doi.org/10.1145/3180308.3180354

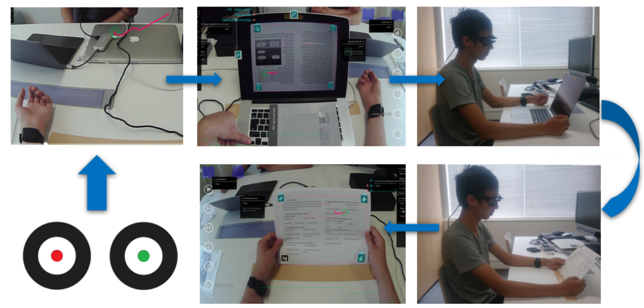

Figure 1. Procedural steps of our study. After calibrating an eye-tracker, participants read documents on screen and paper. We avoided order effects of the two tasks by dividing participants into subgroups.

In this study, we assessed cognitive workload of participants and understandability by using four different measures: The result of multiple choice tests, average pupil size and fixation duration, which were found to be reliable indicators of cognitive workload [3] and tonic component of electrodermal activity (EDA) which application in this research area is quite new. In summary, we could obtain significant differences by comparing these four variables in paper and screen conditions.

EXPERIMENTAL DESIGN
Eighteen computer science students from France, Japan, Ireland and Italy with intermediate to fluent English level and an age between 21 and 27 years participated in our study. Four of them used contact lenses to correct vision. For participation, they received a compensation in value of 1,000 JPY.

Two types of sensors were used, to measure cognitive workload: a wristband E4 and a wearable eye-tracker. The wristband E4 with recording rate of 4 Hz was placed on a non dominant hand of participants and switched on at the begin of each reading task. The binocular Pupil Labs with recording rate of 120 Hz collected fixation duration and and average pupil size. For the reading task on screen, we used a 15-inch retina display. Lightness both in the room and on the screen was kept in the same state. The standardized distance between the used media and participants was 30 cm.

For the experiment, two passages with six related multiple choice questions were taken from two scientific texts with the same difficulty level, length and font style. The order of passages was randomized between participants. We ran-

Table 1. Relative changes of variables in screen condition comparing to paper condition

Variables	The Paper First Group			The Screen First Group		
	Relative Difference	STD	Sig.	Relative Difference	STD	Sig.
Average Pupil Diameter	+10.71%	0.52	.01	+10.91%	0.60	.01
Fixation Duration	+11.64%	1.53	.01	+11.07%	1.60	.01
EDA (Tonic Component)	+73.38%	23.18	.01	+74.49 / -32.90%	7.78/18.10	.01

domly divided participants into two groups (nine participants per group) to avoid any order effects of the used media as following. Participants in *the paper first group* started with a printed document and after reading solved a multiple-choice test presented on paper (paper condition). Then, the second document with subsequent multiple choice test was presented on the screen (screen condition). *The screen first group* did the same procedure in the reversed order as shown in Figure 1. The instruction was to read documents as quick and as attentive as possible. The time limit for each document was 7 minutes and 30 seconds and no time limit for solving tests.

Multiple Choice Test for Understandability Measurement

We combined all answers from paper and screen conditions into two groups. Consequently, group means were calculated and analyzed with the Wilcoxon-Mann-Whitney since the data did not satisfy requirements of t-test.

Average Pupil Size and Fixation Duration Processing

Average pupil size and fixation duration were extracted by Pupil Labs software. In the preprocessing stage, raw data was filtered by 10 Hz low-pass filter and then controlled for outliers. In the next step, we calculated individual means for both variables in paper and screen conditions and run t-test on individual level in both groups. Finally, average pupil size and fixation duration from paper conditions were taken as a baseline for calculation of relative changes in these variables in related screen conditions.

EDA Processing

EDA relates to the sympathetic nerve system (SNS) and increase in physical, emotional or cognitive state can be obtained in rising of EDA signal. Tonic component is one of electrodermal measures which activity is associated with internal information processing [4]. It was processed by the method proposed by Greco *et al.* [5]. The data was filtered by 2 Hz low-pass forward-backward digital filter and then tonic component was extracted. In the next step, we inspected data for outliers. Then, individual mean of tonic component for each condition was calculated and analyzed by t-test. Finally, EDA signal in paper conditions was taken as a baseline for calculation of relative changes in EDA signal in screen conditions.

RESULTS

The rate of correctly given answers in the multiple choice test after reading print documents was 72.2% while after reading documents on screen the results were at 13.9% worse ($p < .05$).

Table 1 shows the relative changes of the variables and p-values of t- test in the screen condition versus paper condition in both groups. In both groups the average fixation duration while reading on screen was significantly higher compared to reading on the paper. The same significantly increase was obtained with the pupil diameter.

In the paper first group, tonic component by reading on screen significantly increased in average to 73.38% compared to the paper condition. In the screen first group, two tendencies in changes of magnitudes in tonic component were obtained: by four participants, the magnitude of tonic component by reading on screen increased in average to 74.49%, while for five participants this magnitude decreased in average at 32.90% comparing to the reading on paper.

DISCUSSION

The results of the multiple choice test show significantly better performance in test solving after reading the documents on paper than on screen, which is consistent with a number of several studies [2]. The findings in the pupil diameter size and fixation duration in our study are consistent with previous studies: in response to rising cognitive workload pupil diameter and fixation duration significantly increase [3]. This result is interesting in the way of natural response of the pupil on the light from computer screen: since the pupil size decreases in response to light source we obtained here an opposite effect comparing it with response on paper. Another interesting finding was done in the screen first group where some participants had significantly higher level of tonic component while reading on paper. This could be explained by the order effect: fatigue from the screen conditions could trigger an increase of EDA magnitude by reading on paper.

CONCLUSION

We present two contributions in the field of designing intelligent user interfaces. First, the results of this study show a significant difference in cognitive workload by the same information processing on screen or paper. Therefore, these findings should be considered more carefully in user interface design in order to make e-learning environment less demanding for users. Secondly, our experiment shows that there are new opportunities to assess mental workload using non-expensive, simple and pervasive devices like EDA wristband.

REFERENCES

1. B. Faghih, M.R. Azadehfar, S.D. Katebi. *User Interface Design for E-Learning Software*.In: The International Journal of Soft Computing and Software Engineering [JSCSE], Vol. 3, No. 3,, January 2014.
2. J. Hou, J. Rashid, K. Lee, H. Kopka. *Cognitive map or medium materiality? Reading on paper and screen*.In: Human Behavior, February 2017.
3. Z. Zhan, L. Zhang, H. Mei, P.S.W. Fong. *Online Learners' Reading Ability Detection Based on Eye-Tracking Sensors*. In: Sensors, September 2016.
4. M. E. Dawson, A.M. Schell, D.L. Filion. *The Electrodermal System*. In: The Handbook of Psychophysiology. Cambrige University, 2007
5. A. Greco, A. Lanata, G. Valenza, E.P. Scilingo, L. Citi.*Electrodermal Activity Processing: a Convex Optimization Approach*. DOI10.1109/EMBC.2014.6944077, August 2014.