Reading Interventions - Tracking Reading State and Designing Interventions

Shoya Ishimaru
Graduate School of Engineering
Osaka Prefecture University
Sakai, Osaka, Japan
ishimaru@m.cs.osakafu-u.ac.jp

Kai Kunze
Graduate School of Media Design
Keio University
Yokohama, 223-8526 Japan
kai@kmd.keio.ac.jp

Tilman Dingler
University of Stuttgart
Institute for Visualization and Interactive Systems
tilman.dingler@vis.uni-stuttgart.de

Koichi Kise
Graduate School of Engineering
Osaka Prefecture University
Sakai, Osaka, Japan
kise@cs.osakafu-u.ac.jp

Andreas Dengel
DFKI
Kaiserslautern, Germany
andreas.dengel@dfki.de

UbiComp/ISWC'16 Adjunct, September 12-16, 2016, Heidelberg, Germany
ACM 978-1-4503-4462-3/16/09.
http://dx.doi.org/10.1145/2968219.2968271

Abstract
The quantified-self movement has brought us a multitude of tracking devices mostly focused on physical activities. But healthy user habits go beyond the physical realm, such as cognitive activities, learning and reading. For installing healthy reading habits we built a wordometer using smart eyewear for tracking online and offline reading activities throughout the day. Besides providing reading statistics at the end of the day we propose a number of real-time interventions to support reading in-situ: adjustable text that takes into account users' current cognitive state, such as attention span, visual fatigue and comprehension levels. In this paper we report insights from our in-the-wild reading tracker and explore various intervention techniques with the goal of supporting user attention, focus, and comprehension in reading tasks.

Author Keywords
reading; context-awareness; quantified mind;

ACM Classification Keywords
H.5.m [Information interfaces and presentation]: misc.

Introduction
"Reading is thinking with someone else's head instead of one's own" Albert Schopenhauer once stated. It opens up new perspectives by taking the reader on a mental journey

for information gain and pleasure. Reading informs, builds vocabulary and even benefits the ability to judge and argue [17]. Especially in today's information age, the skill to efficiently consume, absorb, and evaluate information is more crucial than ever. Throughout our day we constantly engage with written text, be it in the morning newspaper, on car displays, billboards, our desktop computer, cellphone, or smartwatch. It would appear that by instilling healthy reading habits we can help readers be more effective throughout their day.

Acquiring or changing habits is one of the claimed goals of the quantified-self movement. Fitness and sleep trackers, for example, allow us to gain insights into our daily habits in order to be able to take action against unhealthy behavior. However, most of the commercial products and also most of the efforts of the research community have so far focussed on tracking physical activities. Only a handful of proponents have suggested the tracking of cognitive acitvities [11], which can entail attention, mental fatigue, or stress levels. In our work we focus on using eye movements to track reading behavior throughout the day and deriving attention levels during reading.

Schopenhauer's statement above also contains the notion of guiding the reader. By being able to track reading activities throughout the day, we can design systems to better take into account the reader's current level of attention or fatigue. Reading interfaces can process this information in real-time and adjust their presentation to meet the reader's current cognitive state, such as her general receptiveness. By doing so we create in-situ interventions with the goal of increasing reading efficiency. In this paper we describe our approach to track reading throughout the day and across different mediums and start exploring the notion of *reading interventions*. We believe that interventions can be staged

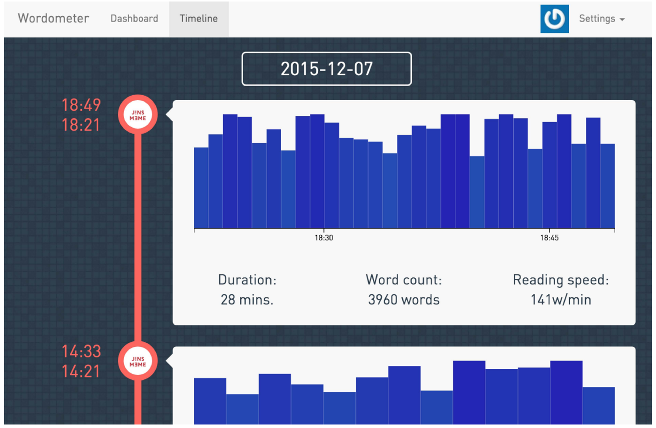

Figure 1: A screen shot image of web based dashboard to look back volumes of reading in everyday.

in such a way that we can

1. facilitate reading tasks,
2. support associated cognitive processes, such as comprehension and recall, and
3. instill healthy reading habits.

Related Work

The strong relationship between reading and eye movements is very well explored in cognitive science and psychology [16, 8]. For example, Kligel et al. investigate correlations of eye fixations with cognitive tasks related to reading [10]. Rayner provides a good summary of eye tracking research [15].

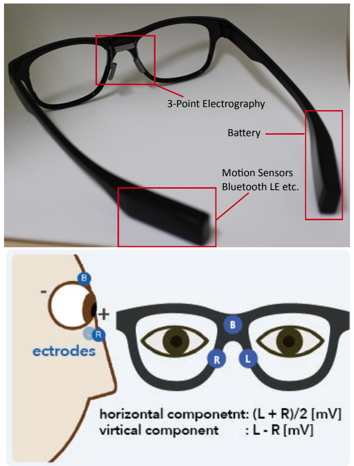

Figure 2: J!NS MEME hardware on top and the positions of three electrodes and formulas to calculate EOG vertical and horizontal component.

In a series of works, Biedert et al. studied ways to enhance the reading experience of the user. They presented Eye-Book [1] and Text 2.0 [2] a reading interface that observe which part of the text is currently being read by the user and that generate appropriate effects (e.g. playing sounds). However, they don't evaluate what suitable interventions are to increase users enjoyment, comprehension or attention. Xu et al. apply eye movement analyzes for document summaries, yet the environment is very controlled, e.g. the users need to rest their chin on a support when performing the reading task [18].

Several researchers also focus on increasing reading speed minimizing the loss of comprehension [4, 9]. To this end, we evaluated several speed reading techniques and stimuli [5].

There are also some efforts to infer the users expertise, language skill and other higher level cognitive activities using eye tracking [12, 14, 3, 6, 7]. Most of the research focusing on second language learners or infants as improvements can be easier tracked using indirect measurements (questionnaires etc.). Our current investigation into reading interventions continues our strand of research looking at how to quantify reading [13].

The Wordometer

One of the metrics to understanding reading habits is volume of reading. We quantify the number of read words as the volume of reading and show them on the visualization as shown in Figure 1. Each bar represents the number of words users read in one minute. From the visualization, users can understand how much they read and when they especially focused to read in segments.

Figure 3: Overview of EOG sensor signal in one-minute recording

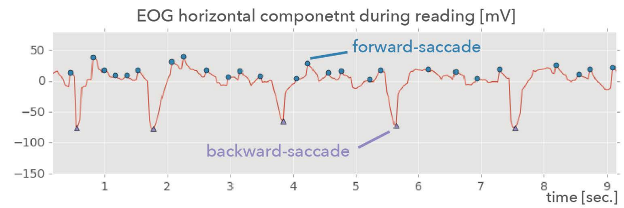

Figure 4: EOG sensor signal during reading. Circle and triangle markers are forward/backward saccade detection's outputs.

Word Counting Algorithm

The word counting algorithm consists of three processes, obtaining a user's eye gaze, detecting forward/backward-saccades, and estimating the number of words he/she read.

To obtain a user's eye gaze, we use J!NS MEME which is connected to a smartphone with Bluetooth low energy. These are affordable technologies and good for long-term recordings. As shown in Figure 2, one reference and two active electrodes are equipped on J!NS MEME. EOG vertical component is calculated as an average of two electrodes, and EOG horizontal component is calculated as a difference between them.

Figure 3 shows an overview of EOG horizontal component in one-minute recording that includes reading activity. Negative values represent eye movement right to left, and positive values represent eye movement left to right. Regular

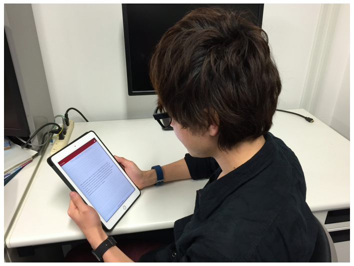

Figure 5: A user reading on a tablet with J!NS MEME.

Subject	Error rate	STD
a	14 %	1.6 %
b	24 %	2.1 %
c	15 %	1.8 %
d	15 %	1.7 %
e	12 %	1.4 %
Ave.	16 %	1.7 %

Table 1: Estimation results on user-dependent approach

patterns of eye movement will appear during reading activity because of line breaks.

We detect these saccades to forward and backward from sensor signals as shown in Figure 4. For forward-saccade detection, we filter the sensor signal with median filter to remove noises. After filtering, we apply peak detection algorithm to detect forward-saccades. Backward-saccade is detected if the sensor value is lower than a threshold which is decided dynamically. The threshold is calculated as the difference between mean value and variance value of sensor values in a small window (the window size is one second).

The number of words a user read is estimated by linear support vector regression. Four features are calculated for the regression, the total count of forward-saccades, mean EOG signal value of forward-saccades, the total count of backward-saccades, and mean EOG signal value of backward-saccades.

Evaluation

As an initial evaluation before long-term recording, we evaluated our word counting algorithm with a dataset on fixed condition. We recruited 5 participants to read English essays on iPad wearing J!NS MEME (see Figure 5). Every subject read 38 paragraphs during the recording. So the total amount of paragraph in the dataset was 190 (minimum: 27, maximum: 120, average: 60 words in one paragraph). The sampling frequency of EOG signal from J!NS MEME was 11 Hz. Training and testing were done on both user-dependent and user-independent approach. On an user-dependent approach, data from each subject are used as training for his/her reading. On the user-independent approach, all data from all subjects are used as training. Evaluations were done with 10-fold cross validation.

Table 1 shows the estimation errors and standard deviations on user-dependent approach. The average error of five participants was 16% (9.6 words in 60 word's paragraph). The estimation error on user-independent approach was 18% with 1.7% STD. Reading recognition and quantification is the first step towards building applications dealing with this type of data. One of the focuses of our future work now is the creation of reading interventions based on the assumption that reading is tracked in real-time and underlying text is dynamic, such as on tablets.

Reading Interventions

There is a multitude of information the tracking of eye movements can give us about the cognitive state of readers. For example, blinking rates give us insight into visual fatigue levels [15]. So as readers are getting more tired their eye blinking rate rises. Such fatigue is often temporary and can be met with a distraction task, such as standing up, putting down the book and stretch for a few minutes. Also getting some fresh air or water could be one of the recommendations to regain the ability to concentrate. In the following we will describe potential interventions:

For one, we can aim at increasing comprehension: nudge readers to pause after stretches of reading to reflect on what has just been read. Such behavior further fosters later recall of that content.

On similar note, pupil dilation corresponds to engagement and attention levels. This can be used in two ways: 1) as summary metric where text that was read with high attention level might be summarized with more detail than text that was comparatively less intensely attended to (assuming that attention correlates with the reader's interest in the content) and 2) as feedback mechanism to authors and publishers to refine their content according to readers' attention (this could also comprise ads being priced higher to reach people with high attentiveness).

Regressions - i.e. re-reading of words, sentences, or entire passages - account for about 15% of the reading time. Although being helpful for comprehension, it often turns into a habit that slows down the reading process. Simply being aware of regressions through a feedback mode could encourage readers to keep going forward through text and thereby increasing their reading speed. In-situ reading stimuli can be applied in order to encourage users to keep or increase their reading pace [5].

Experiments

To test and assess the effects on reading we are planning a series of user studies based on the reading intervention techniques presented. Therefore, we are currently developing a synchronization feature that pairs the eye tracking data from J!NS MEME glasses with the reading application running on a tablet device. That way we can stage interventions visually, through haptic feedback as well as through audio cues. In lab studies we will collect subjective user feedback and reading metrics to single out useful interventions. For long-term assessment we will hand out devices to study participants over longer periods of time where we will collect data in the wild about people's reading habits throughout the day, but also about their experience with reading interventions when being used in combination with our complementing app.

Conclusion

In this paper we presented an extension of our initial Wordometer technology (detecting how many words a user reads) to a wearable, unobtrusive eye wear (J!NS MEME) and outlined a couple of reading interventions suitable for this setup. In the intermediate next steps we need to extend our experimental setup to a larger, controlled set to evaluate our basic technology more. As outlined in the previous section we plan to study reading in the wild to first of all understand what are healthy reading habits and then to improve them.

References

[1] Ralf Biedert, Georg Buscher, and Andreas Dengel. 2010a. The eyebook–using eye tracking to enhance the reading experience. *Informatik-Spektrum* 33, 3 (2010), 272–281.

[2] Ralf Biedert, Georg Buscher, Sven Schwarz, Manuel Möller, Andreas Dengel, and Thomas Lottermann. 2010b. The text 2.0 framework: writing web-based gaze-controlled realtime applications quickly and easily. In *Proceedings of the 2010 workshop on Eye gaze in intelligent human machine interaction*. ACM, 114–117.

[3] Andreas Bulling and Thorsten O Zander. 2014. Cognition-Aware Computing. *Pervasive Computing, IEEE* 13, 3 (2014), 80–83.

[4] Oscar de Bruijn and Robert Spence. 2000. Rapid serial visual presentation: a space-time trade-off in information presentation. In *Advanced visual interfaces*. 189–192.

[5] Tilman Dingler, Alireza Sahami Shirazi, Kai Kunze, and Albrecht Schmidt. 2015. Assessment of Stimuli for Supporting Speed Reading on Electronic Devices. In *Proceedings of the 6th Augmented Human International Conference (AH '15)*. ACM, New York, NY, USA, 117–124. DOI:http://dx.doi.org/10.1145/2735711.2735796

[6] Tamara van Gog, Liesbeth Kester, Fleurie Nievelstein, Bas Giesbers, and Fred Paas. 2009. Uncovering cognitive processes: Different techniques that can con-

tribute to cognitive load research and instruction. *Computers in Human Behavior* 25, 2 (2009), 325–331.

[7] Shamsi T Iqbal, Xianjun Sam Zheng, and Brian P Bailey. 2004. Task-evoked pupillary response to mental workload in human-computer interaction. In *CHI'04 extended abstracts on Human factors in computing systems*. ACM, 1477–1480.

[8] David E Irwin. 2004. Fixation location and fixation duration as indices of cognitive processing. *The interface of language, vision, and action: Eye movements and the visual world* (2004), 105–134.

[9] Marcel A Just, Patricia A Carpenter, and Jacqueline D Woolley. 1982. Paradigms and processes in reading comprehension. *Journal of experimental psychology: General* 111, 2 (1982), 228.

[10] Reinhold Kliegl, Antje Nuthmann, and Ralf Engbert. 2006. Tracking the mind during reading: the influence of past, present, and future words on fixation durations. *Journal of Experimental Psychology: General; Journal of Experimental Psychology: General* 135, 1 (2006), 12.

[11] Kai Kunze, Masakazu Iwamura, Koichi Kise, Seiichi Uchida, and Shinichiro Omachi. 2013a. Activity Recognition for the Mind: Toward a Cognitive "Quantified Self". In *Computer*, Vol. 45. 98–101.

[12] K. Kunze, H. Kawaichi, K. Yoshimura, and K. Kise. 2013b. Towards inferring language expertise using eye tracking. In *Ext. Abs. CHI 2013*. 4015–4021.

[13] Kai Kunze, Katsutoshi Masai, Masahiko Inami, Ömer Sacakli, Marcus Liwicki, Andreas Dengel, Shoya Ishimaru, and Koichi Kise. 2015. Quantifying reading habits: counting how many words you read. In *Proceedings of the 2015 ACM International Joint Conference on Pervasive and Ubiquitous Computing*. ACM, 87–96.

[14] Pascual Martínez-Gómez and Akiko Aizawa. 2014. Recognition of understanding level and language skill using measurements of reading behavior. In *Proceedings of the 19th international conference on Intelligent User Interfaces*. ACM, 95–104.

[15] Keith Rayner. 1998. Eye movements in reading and information processing: 20 years of research. *Psychological bulletin* 124, 3 (1998), 372.

[16] George D Spache. 1962. Is This a Breakthrough in Reading? *The Reading Teacher* 15, 4 (1962), 258–263.

[17] KE Stanovich and AE Cunningham. 1998. What reading does for the mind. *American Education Journal* (1998).

[18] Songhua Xu, Hao Jiang, and Francis C.M. Lau. 2009. User-oriented document summarization through vision-based eye-tracking. In *Proc of IUI (IUI '09)*. 7–16.