Private Reader: Using Eye Tracking to Improve Reading Privacy in Public Spaces

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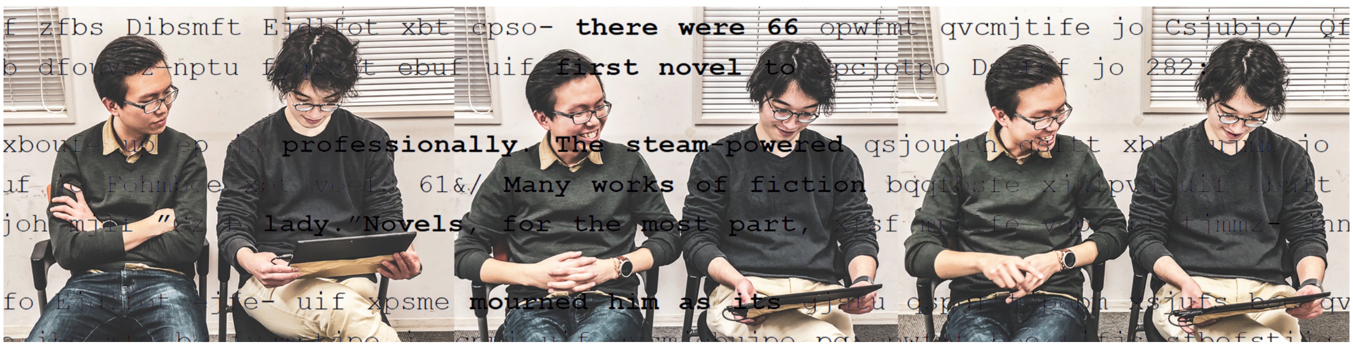

Figure 1: The Private Reader Concept: Using Eyetracking to make successful "Shoulder Surfing" more difficult.

ABSTRACT

Reading in public spaces can often be tricky if we wish to keep the contents away from the prying eye. We propose Private Reader, an eye-tracking approach towards maintaining privacy while reading by rendering only the portion of text that is gazed by the reader. We conducted a user study by evaluating for both the reader and observer in terms of privacy, reading comfort, and reading speed for three reading modes; normal, underscored, and scrambled text. "Scrambled" performs best in terms of perceived effort and frustration for the shoulder surfer. Our contribution is threefold; we developed a system to preserve privacy by rendering only the text at gaze-point of the reader, we conducted a user study to evaluate user preferences and subjective task load, and we suggested several scenarios where Private Reader is useful in public spaces.

CCS CONCEPTS

• **Human-centered computing → User interface programming**; *User studies*; *Interaction paradigms*; Systems and tools for interaction design.

KEYWORDS

privacy, eye tracking, public space, display, tablet, shoulder surfing, eye gaze, reading, text interactions

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1 INTRODUCTION

Have you ever been in the subway, train or airplane and had the uncomfortable feeling that a neighbor is prying on your phone, tablet or laptop? In recent years, privacy concerns are on the rise for individuals, as especially in our digital age, the capture and sharing of sensitive personal information are easier and easier [18]. Virtually everyone carries a smartphone in their pockets or a laptop or tablet in their backpack, which are often used for light reading or checking the social media in public spaces. During such a scenario, it is inevitable for nearby observers, purposely or not, to catch a glimpse of the content shown on the display. Eiband et al. found that observers generally prefer to read text, followed by pictures and games [5]. In most cases, this act does not contain malicious intent and is usually fueled by curiosity, though it does evoke negative feelings.

We developed Private Reader, a method to reduce comprehension, increase frustration for the observer yet maintaining readability for the user (not impacting the reading speed). We achieve this

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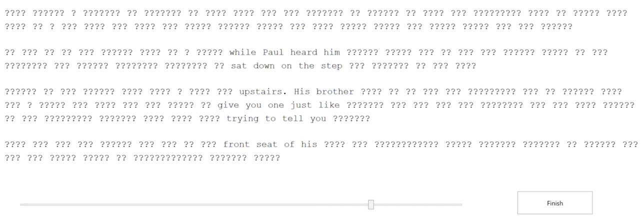

Figure 2: The Diameter Pilot Study interface. The slider on the bottom determines the size of the diameter of unscrambled words around the gaze ppint.

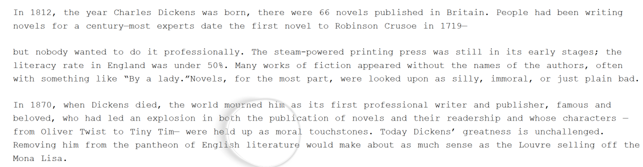

Figure 3: The "normal reading" interface, the user gaze is shown as a bubble for illustration purposed only

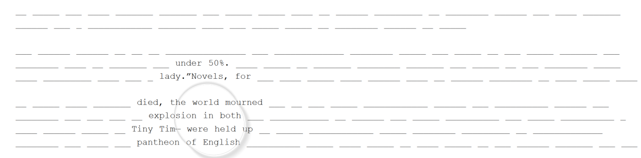

Figure 4: The "Underscored Private Reader" interface, the user gaze is shown as a bubble for illustration purposed only

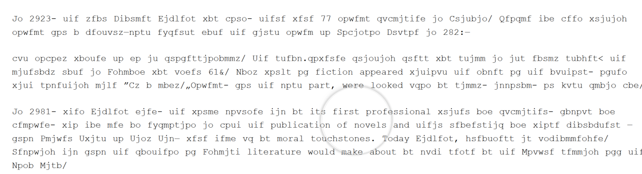

Figure 5: The "Scrambled Private Reader" interface, the user gaze is shown as a bubble for illustration purposed only

by tracking the gaze point of the reader on the display, and rendering only what the user is currently reading. We also add noise -scrambling words- to make it harder for the attacker. In most cases, the use of eye gaze tracking is seen as a privacy concern [17].

We believe eye gaze can also increase privacy. For Private Reader, we leverage the critical benefit of eye tracking, which is knowing exactly where only the reader is reading, for private use. Only the content of the particular gaze point is rendered on the display correct, whereas other text passages are made unreadable for observers in the near vicinity. We present Private Reader, proof-of-concept implementation using commodity devices to increase privacy in public settings in public transportation (bus, train, subway,...) while maintaining most of the readability and keeping reading speed and text comprehension compared to standard reading on digital devices. Our contributions in this work are the following:
(1) We present a novel approach that increases reading privacy on mobile devices using eye tracking
(2) We developed two prototype implementations for Private Reader: underscored and scrambled.
(3) We ran a user study to compare different implementations of Private Reader in terms of speed, privacy, and perceived workload. It seems the "scrambled" Private Reader implementation is a good compromise regarding reading speed, privacy, effort, and frustration.

2 APPROACH

We use eye tracking to render only the word a user is currently reading as a core concept. Current commodity eye-tracking devices cannot provide this level of accuracy; we need to also show a couple of words around the user's gaze. The straight forward approach is to display these couple of words in a circle around the gaze. This idea is similar to the Eyespot concept by Khamis et al. [10]). Yet, their setup is utilizing a high precision, high-speed wearable eye tracker. To make it more difficult for an attacker, we can also introduce additional noise showing changing words/characters on the part of the screen where the user is not looking.

Private Reader must be usable on a mobile device to reinforce its use in public spaces. Our rendering implementation is also inspired by perceptually guided scrolling, which wipes out text that has already been read [19].

3 PRIVATE READER PROTOTYPE

Based on the discussion in the approach section and related work, we developed two versions of Private Reader:

Underscored. - Text outside of the gaze point is rendered as the underscore symbol, making only the text at the gaze point readable.

Scrambled. - Text outside of the gaze point shows scrambled text, where a word looks like a collection of random letters. We first implemented a prototype that replaced a word with a different random word. We run into trouble with proportionally spaced fonts rendering. Paragraphs and sentences would change in length, making the text on the page "jump around." One possible solution is to use Monospaced fonts. They hurt reading speed [1]. Another solution for future work is to calculate word lengths based on the proportional font used.

Figure 6 (middle) shows the prototype system implemented and used for the user studies. We use a Windows Surface Pro 6 Tablet with a Tobii 4C eye tracker attached. We obtained a Tobii 4C research license to use the system for this publication. The Tobii 4C is a standard commercial eye tracker with an approximate sampling rate of 60Hz for the gaze data.

Figure 6: An application scenario for Private Reader (left). The current Private Reader prototype: a Surface Tablet with a Tobii 4C attached (mid) and a picture from the experimental setup (right).

4 USER STUDIES

We first present a pilot to determine the size of the diameter for displaying words on the display. For our user study, we look into evaluating the usability, subjective experience, and privacy of Private Reader, as well as perceived workload for both the user and observer.

4.1 Pilot Study

As current commercial eye tracker technology is not accurate enough to detect which word a user is focusing on, we need to render a couple of words around the estimated gaze point. We ran a pilot study to determine the optimal diameter around the gaze point. We recruited 6 participants (3 female, average age 23, std 3) and showed them the reader interface in Figure 2. The can read a couple of lines of text and adjust the diameter of displayed words with a slider at the bottom. Average size of the diameter was 3.85 cm (180 pixels at 120 dpi) (std 1.1 cm, 55 pixels), this was also used for the following reading study.

4.2 Reading Study

Twelve participants (6 female, mean age 25, std 6) took part in our study, all fluent in English (high-school degree or higher, no native speakers). Two participants joined one experimental run together split into the roles "user" and "observer." Both sit next to each other, and the user will read a text normally (as baseline) as well as two other texts with our two Private Reader prototype implementations. The observer sits next to the user (close similar to a public transport situation) and tries "shoulder surf" while the user reads. The reading type: normal, underscored, scrambled, and the type of English text are counterbalanced using the Latin Square approach.

For English texts, we are using reading comprehension texts from the TOEFL. Users and observers have to separately answer comprehension questions associated with the texts (3-4 questions depending on the texts).

At the beginning of the experiment, the user and observer are briefed by the experiment conductor about the setup and fill out the consent form as well as background information about them (sex, age, reading habits). After each reader modality trial (normal, underscored, scrambled) the users and observers participate in an informal interview about the modality asking about their experience, the usability (over the System Usability Scale[2]), as well as a NASA TLX questionnaire to assess the perceived task load. At the end of the experiment, the conductor carries out another checkout interview comparing the different reading modalities and gathering qualitative feedback.

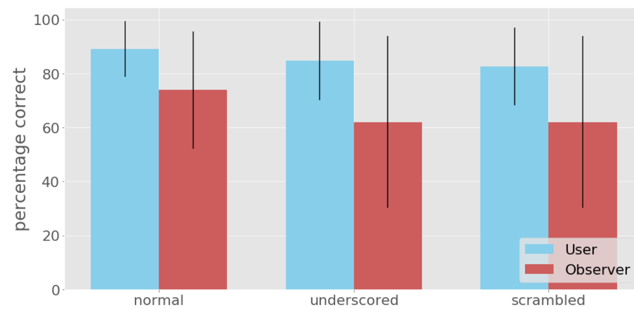

Figure 7: Average percentage of correctly answered comprehension questions for the English texts for the different reading types, user and observer.

As mentioned, we use the Surface Pro with Tobii 4C as a computer for the experimental setup. Although possible, we don't record eye gaze during the experiment, as the system gets uncomfortably hot and we would need to plug in a power cord. After initial tests with users and different "Private Reader" implementations, we decided against the recording to make the experiment more realistic and less obtrusive for the users.The experiments were approved and conducted in accordance with the Ethics board of Keio Media Design, Keio University.

5 RESULTS AND DISCUSSION

The participants needed between 2-10 min to read a text with the private reader prototypes taking on average 1-2 min longer compared

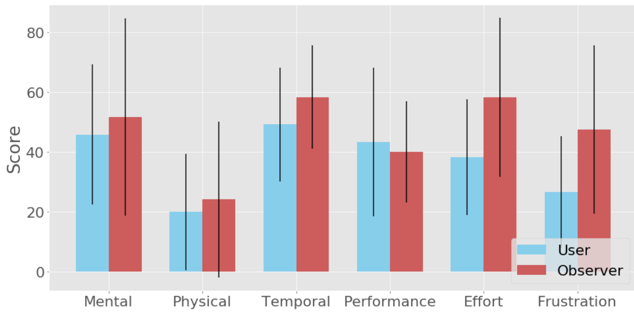

Figure 8: The average Nasa TLX scores with standard deviation for the normal reading experience (reference) for the user and the observer (shoulder surfer).

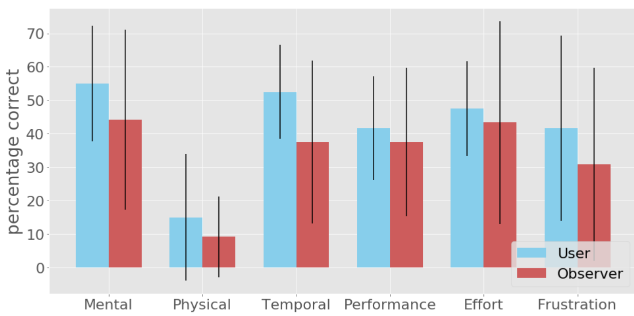

Figure 9: The average Nasa TLX scores with standard deviation for the underscored Private Reader for the user and the observer(shoulder surfer). We add the Tobii eye gaze bubble as a reference to the picture; it is not shown during the experiments.

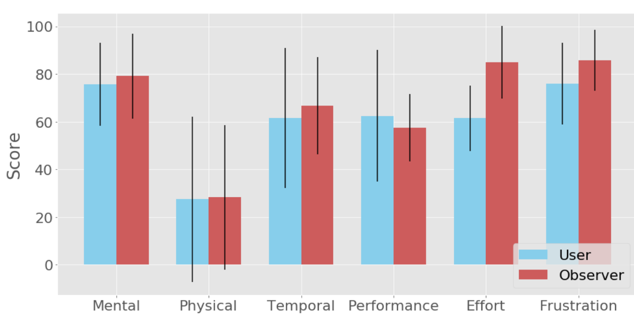

Figure 10: The average Nasa TLX scores with standard deviation for the scrambled Private Reader for the user and the observer (shoulder surfer). We add the Tobii eye gaze bubble as a reference to the picture; it is not shown during the experiments.

to baseline (not statistically significant). There was also no statistically significant difference between the average reading speeds for the individual modalities. The average reading speeds are as follows: for normal reading 258.11 WPM (std 80.12), for underscore 252.11 WPM (std 91.23), and for scrambled 248.32 WPM (std 98.63). All seem all a bit high, yet most of the participants were no English native speakers. A similar picture can be seen with the Usability Scale scores: 70 (std. 5) for normal reading (considered above average), 72 (std. 8) for "Underscored" (above average) and 66 (std. 6) for "Scrambled" (just below average). These scores are also not significant. Unscrambled scores slightly higher as two users prefer it to normal reading. they say it makes them focus, see discussion below. Overall, the feedback to our prototype was positive.According to the structured interview after the experiments; participants can imagine using it in public scenarios. Except for one user who had calibration trouble in one of the trials. Most users mentioned traveling in subway, train, and bus as useful scenarios where they would like to use the system. Waiting in line also came up as another user scenario.

Figure 7 shows the percentage of correctly answered comprehension questions overall modalities and user/observer. The results are not statistically significant. The observer still performs very well. Yet, the experimental setup favors the attacker. The observer knows when the user starts reading and the observer needs to pay full attention. If he misses the beginning, or any part, it is not possible for him to reread the information for the private reader cases.

The Nasa TLX scores are summarized in Figures 8,9,10.Interestingly, the underscored Private Reader, similar to the EyeSpot concept [10] scores better for the observer for perceived effort, frustration, and mental load. This result seems contrary to our goal. Discussing with the observers who rated these values particularly low, they mentioned that the underscore helps them to know when the user starts reading and how fast they are reading (giving them an easy way to focus on the text and adjusting better to the user's speed). P5 (observer): "It's easy to spy as it's easy to see where the user is looking at." The comprehension scores of the underscored reader are lower than normal reading. The difference in effort between normal and scrambled reading is statistically significant ($F(1, 10) = 11.2, p = 0.007$) for the observer, the same holds for the frustration scores ($F(1, 10) = 39.93, p = 0.00008$). This difference underlines our intent to make it harder for the observer to shoulder-surf. There are no other statistically significant results.

One user mentioned that she enjoys the underscored Private Reader, not for the privacy mode, but focused reading. She felt she could concentrate better on the text with all other words gone. Another user also mentioned that he didn't like the normal reading mode as it "somehow felt more demanding." One participant recommended trying the underscore mode with people suffering from dyslexia as it might help them or implement the reverse (scrambling the words you are looking at) to give people the feeling and empathy about dyslexia. A significant usability concern raised by the users were related to inaccurate eye gaze calibration, and the current prototype hardware as the Tobii 4C is longer than the Surface Pro. This problem can be remedied by using a smaller or integrated eye tracker.

6 RELATED WORK

There is much related research towards increasing privacy when consuming digital content, mostly focusing on password-related input [11, 24]. Eye tracking has also been explored either as a form of interaction or even to contribute towards preserving privacy. Khamis et al. present a concept very close to our research called Eyespot[10]. Eyespot shows the content of a mobile-phone screen only around the user's gaze position (very similar to the "UnderscorePrivate Reader"). In contrast to their work, we implemented another modality "Scrambled Reader," we are using a commodity device, not a wearable eye tracker and natural reading posture. We also evaluate not only the user's comprehension, reading speed and comfort, but also that of an attacker. In the following, we will explore related works in privacy and eye tracking.

6.1 Privacy

Privacy is a primary concern in the HCI community. For example, there have been several researchers on shoulder surfing, which is the act of spying on others usually to obtain private and personal information [9, 30]. Public displays have been a critical focus area. Frederik et al. [3] developed a system using a variety of approaches such as partially blocking the display, an indicator when there is an observer present, as well as mirroring the observer's position and orientation on the screen. Tan et al. [27, 28] also tackled the issue of privacy on public display, though more on the keyboard input direction. Looking at screens on personal devices, Tarasewich et al. [29] developed a web plugin that renders a blinder for sensitive information on a browser. Eiband et al. [5] established a few critical guidelines for privacy protection, namely that it should be easy to use and subtle enough to be socially acceptable. Saad et al. are using the front facing camera in mobile devices to detect potential shoulder surfers and present strategies to notify the user [26].

Another more straightforward approach is to use a polarization filter to protect the privacy of the reader, however this can affect readability as the filter blocks out light from certain angles.

6.2 Eye Tracking

Eye tracking has been widely researched in mobile HCI primarily as input and interaction mechanic [7, 8, 14, 20–23, 25]. There is extensive work, on eye gaze interactions on tablets, for example from Roetting.[25] Khamis et al. present a recent comprehensive summary regarding gaze-based interaction on mobile devices[8]. Additionally, Pfeuffer et al combine gaze interactions with multi-touch gestures.[22]

Regarding the use of eye tracking for privacy matters, iType uses eye gaze tracking for typing private information as opposed to input with fingers [16]. However, it was primarily evaluated on its accuracy and its performance instead of its degree of privacy. This approach has also been studied by Forget et al. [6], where selection is performed with eye gaze and activation is achieved with space-bar input from the keyboard. Kumar et al.[12] also use eye gaze as the input method for passwords, arguing that it is harder to follow then somebody's fingers.

There exist also a few works that focus on eye-gaze based interactions and analysis while reading texts [4, 13–15, 19]. For example, Leiva et al. present adaptive "Snippets" using eye tracking to support skimming on mobile devices utilizing responsive text summarization [15]. They don't focus on privacy-related features.

7 CONCLUSION AND FUTURE WORK

We present the Concept "Private Reader," as well as two implementations (underscored and scrambled) using a commercially available eye tracker and tablet. In a user test, we compared them to a normal reading experience, comprehension, and perceived task load of both user and observer. Our results underline especially the effectiveness of the scrambled reader prototype. The prototype system is already fully functional, can be loaded with different texts and used in public scenarios like the subway (see Figure 6 left). In the future, we want to include not only word scrambling, but word replacing. As mentioned before we had trouble with word length (not mono-spaced fonts) as text and paragraphs were "jumping" on screen. Alternative options of text obfuscation include the use of special fonts that have unreadable characters with matching size, e.g., by overlaying horizontally or vertically mirrored characters, using blurred characters, or stacked characters that were vertically squashed. Also, dyslexia and focus recommendations from participants seem also interesting directions for future work.

8 ACKNOWLEDGEMENTS

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