Open your Eyes: Blink-induced Change Blindness while Reading

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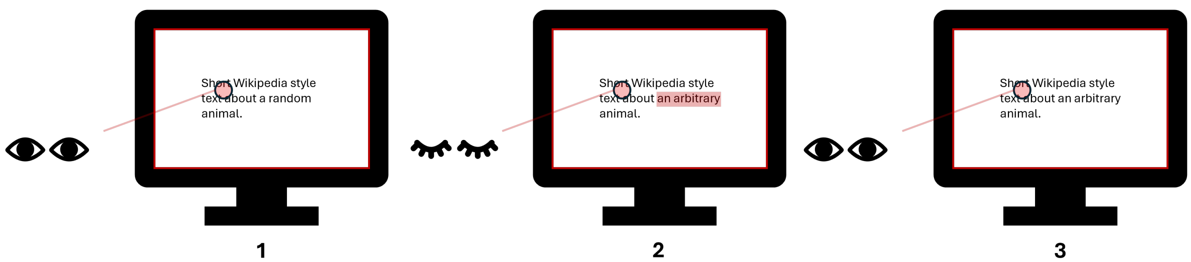

Figure 1: Blink-induced change blindness while reading. In an experiment, (1) Eye movements are tracked while the participant reads a short text excerpt. (2) Once the participant blinks, the text is changed based on the current gaze position. (3) At the end of the experiment, the participant is asked if there were any noticeable changes in the text.

Abstract

Reading assistants provide users with additional information through pop-ups or other interactive events which might interrupt the flow of reading. We propose that unnoticeable changes can be made in a given text during *blinks* while the vision is obscured for a short period of time. Reading assistants could make use of such *change blindness* to adapt text in real time and without infringing on the reading experience. We developed a system to study blink-induced change blindness. In two preliminary experiments, we asked five participants to read six short texts each. Once per text and during a blink, our system changed a predetermined part of each text. In each trial, the intensity and distance of the change were systematically varied. Our results show that text changes — although obvious to bystanders — were difficult to detect for participants. Concretely, while changes that affected the appearance of large text parts were detected in 80% of the occurrences, no line-contained changes were detected.

CCS Concepts

• **Human-centered computing** → *Ubiquitous and mobile computing systems and tools*; • **Computing methodologies** → **Perception**.

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Keywords

blinking, change blindness, eye tracking, reading, comprehension

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1 Introduction

Reading can feel daunting when the text introduces unfamiliar concepts, uses a confusing style, or lacks engaging content [1, 8, 11, 15, 23, 27]. *Reading assistants* improve reading experiences and help readers understand complex expressions [4, 19, 24, 26]. However, they often require explicit user interaction and typically introduce easily noticeable changes. Far from providing calm background assistance, they rather interfere with the reader's state of *flow* [5]. For a more seamless reading experience, we propose that a reading assistant, which does not require explicit interaction and introduces unnoticeable changes, might be favorable.

Change blindness is described as the inability to detect large changes in visual scenes [20], which was previously studied in the context of reading [14, 26]. McConkie and Zola have shown that the readers are unaware of specific changes if they occur during saccades [14]. Wilson et al. noted that changes in text are not always noticeable when they occur sufficiently far from the reader's point of interest [26].

In virtual reality (VR) environments, blink-induced change blindness has been explored [22, 28], for example, to redirect the walking direction of users by up to 5 degrees without them noticing [13]. Similarly, significant visual changes in digital images may remain unnoticed when they are made while the observer blinks [16]. Building on these findings, we argue that such blink-induced change blindness could also be leveraged to provide readers with less intrusive assistance. For instance, when a reader struggles with a term or paragraph in a text, we might extend the original text — during a blink — with a sentence that explains this term. This might permit the provision of assistance for the reader to better understand the original text without them even noticing the change. However, before providing such assistance, we first need to systematically investigate the feasibility of changing text during blinks without readers noticing.

To this end, we present an initial investigation of blink-induced change blindness in the context of reading. As a proof of concept, we present a gaze-assisted system that detects blinks and rapidly alters a given text in real time (Figure 1). We evaluated our system with five participants and found that these participants remained unaware of changes if they occurred at a distance of at least one paragraph and did not affect the outline of the paragraph.

2 Related Work

Change Blindness when Reading. McConkie and Zola studied capitalization changes during *saccadic* eye movements [14], so the reader would read a text that would change rapidly between "hElLo mY NaMe Is cHaRlIe" and "HeLlO My nAmE iS ChArLiE". They found that although evident for bystanders, the change was not observable by the readers themselves [14]. However, Rayner showed that this effect does not work with replacing words [18]. This indicates that the change blindness induced by saccades does not allow for more sophisticated text alteration.

Change Blindness when Blinking. More recently, researchers studied change blindness and blinking in VR environments [13, 22, 25, 28]. Khumsan et al. found that using blink-induced change blindness in redirected walking, they could move walls up to 0.90 meters without participants noticing such architectural changes [25]. Regan et al. examined whether people notice changes in high-resolution displays of everyday visual scenes if they occur during a blink [16]. They found that even when observers were directly fixated on change locations (within 1 degree), more than 40% of the time, they still failed to notice these changes [16]. These findings substantiate our hypothesis that blink-induced change blindness might also be used in the context of reading.

Reading Assistants. Today, there are different approaches that aim to support readers [3, 4, 6, 7, 10, 19, 24, 26]. Using Augmented Reality, Thaqi et al. proposed a Smart AI reading assistant (SARA) that tracks eye movements when reading and displays virtual overlays with further information if it detects reading difficulty [24]. Similarly, a gaze-enabled augmented reality (GEAR) system [2] can recognize user activities (e.g., reading, inspection, search) from their eye movements and provide them with a translation of the text being read [3]. Sibert et al. developed a system that uses visually controlled auditory prompting to help the user with the recognition and pronunciation of words [19]. Another approach uses the predictability of linear reading and allows continuous gaze-assisted reading without requiring manual input to scroll [26]. Fok et al. support the skimming process by highlighting some key aspects in a paper to direct the reader's attention [7]. These studies demonstrate a growing interest in improving the reading experience and the wide range of solutions. However, the adaptations in these solutions are often easily noticeable and thus might interrupt the reading experience. We propose a new approach to reading assistants where our prototype leverages change blindness to alter the text during eye-blink events, enabling an uninterrupted reading experience that is personalized in real time.

Figure 2: In our system, a *Pupil Core* mobile eye tracker provides real-time data via a ZMQ-socket, a *pipeline* prepares the data and propagates it via a Websocket, and an *HTTP Server* handles the serving of the client content. The *client* application receives the data and dynamically changes the displayed content from a *database* as needed.

3 Implementation

Our prototype system (see Figure 2) features a *real-time data processing pipeline* that detects blink events from data captured by a *mobile eye tracker* and a *client* that displays and modifies the text.

Mobile Eye Tracker. The Pupil Core glasses [9] are frequently used in eye-tracking research. They provide two infrared cameras that are pointing at each eye, and a forward-facing camera capturing the world view. The data is broadcast via a ZMQ socket. The need for a mobile solution is already evident, as people read on many devices and in different physical or Mixed Reality environments.

Pipeline. The real-time data from the glasses is streamed to dedicated services that filter and prepare the data before forwarding it via a Websocket. We differentiated between blink[1] and fixation events[2]. While blinks are represented as plain booleans, fixation events are described by their location (x, y), dispersion and duration.

Client. The text is displayed by a simple Web app: an HTTP server provides static HTML pages, as seen in Figure 2. To allow proper gaze mapping, each text is divided into multiple smaller paragraphs of roughly 2-3 sentences, which are enclosed in separate *<span> elements* [3]. The client application handles events received

[1]https://docs.pupil-labs.com/core/developer/network-api/#blink-messages
[2]https://docs.pupil-labs.com/core/developer/network-api/#fixation-messages
[3]https://developer.mozilla.org/en-US/docs/Web/HTML/Element/span

via the Websocket connector and is divided into two modules. The gaze module tracks the position of gaze on the screen and identifies the part of the text (e.g., line or paragraph) that is currently read. The blink module waits for a *blink onset event* and updates the paragraph at a predefined distance depending on the experimental parameters (e.g., how many changes should occur in the given text).

4 User Experiments

We used our prototype system to study blink-induced change blindness in the context of reading. We used a within-subject experiment setup with five participants (age: $M = 26.0$, $SD \approx 0.7$; three men, two women). In line with our university's regulations, no formal approval from the university's ethics committee was required. Participants, while wearing the Pupil Core eye tracker, were asked to read short descriptions of animals and answer three simple questions about the animal. The text content was extracted from Wikipedia and the follow-up questions were designed to encourage participants to read attentively. For consistency, each text was formatted similarly: separated into two columns with four paragraphs per column with a length of two to three sentences. During each reading task, following a successfully detected blink event, a part of the text was changed with respect to the current gaze position of the participant.

Change Intensity and Distance. To study the noticeability of changes in a text, we differentiated between three types of change intensities at two distance levels. We define the *intensity* of a change as the extent to which the change alters the visual appearance of the text block. *Line-contained* changes affect only the layout of the line where it happened and replaces words with other words of the same or similar length (Figure 3a). *Inner paragraph* changes affect multiple lines in a paragraph, but the paragraph's overall silhouette remains unchanged (Figure 3b). *Outer paragraph* changes affect the text's overall structure, e.g., by adding or removing lines from a paragraph or rewriting them with longer or shorter sentences (Figure 3c). Furthermore, to determine the noticeability of these changes, we tested two different *change distances.* As we are working with short paragraphs, we tested changing the currently looked-at paragraph and the following paragraph. This gave us a good overview of the spatial characteristics needed to exploit change blindness to augment the text.

4.1 First Experiment

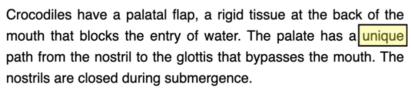
Each participant was seated in front of a 15-inch monitor that is roughly centered at eye level at a distance of about 70 cm. After the default five-point calibration procedure, we let each participant read some unrelated text to check the calibration and repeat this procedure if necessary. At the start of the experiment, participants were instructed to carefully read the texts they were about to see and then answer three comprehension questions. However, the answers were not recorded and analyzed because text comprehension is beyond the scope of this study. They then went through six trials (all combinations of *change intensity* and *distance*). To have an authentic reading scenario and prevent participants from priming, they were not made aware that the text could change while they read. To achieve a binary result (i.e., change noticed or not), each text was changed only once. After each trial, the participants were asked the question *"How was the reading experience?"* and we recorded their response. Then they pressed the *Next* button (Figure 2) to continue to the next trial. At the end of the experiment, we debriefed the participants and unveiled the actual intent of our study. Then we asked them how they feel about text altering without them noticing and if they feel like it could be a useful tool to assist readers. Each participant read the text in the same order, and the texts with smaller changes in the following paragraph were read first. In this way, we minimized the possibility that participants would notice changes and alter their reading behavior.

Results. No participant noticed the change if it was *Line-contained* and in the *following* paragraph (see Figure 4). Only one participant noticed the *Inner paragraph* changes occurring in the *following* paragraph. Three participants noticed *Outer paragraph* changes in the *following* paragraph. All participants mentioned being susceptible to changes in the overall structure, such as shifts in paragraph positions. Although no participant could exactly point out what changed, positional shifts in the paragraphs were noticed. The changes in the *current* paragraph were more noticeable: all participants noticed the *Line-contained* changes, and four participants noticed the *Inner paragraph* and *Outer paragraph* changes. All participants reported that our system could be useful in adapting the text to have a better reading experience. They also stated that substituting words for synonyms would limit the usefulness of the system. Adding explanatory sentences that fit into the surrounding text was welcomed.

4.2 Second Experiment

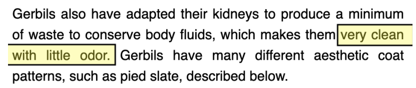
Given the short duration of a blink and the response latency of our system (see Section 5), the participants were tasked with repeating the experiment with a slight modification. Once a blink onset was recorded, a white overlay was rendered for 20 ms to counteract any delay in the detection of blinks. When the blinks were long enough, the participant did not see the overlay. In cases where the blink event would have been received too late, the overlay acted as *simulated blink*, visually obscuring the change. In this experiment, we removed the constraint of only one change per text and allowed all blink-induced changes. Since all participants were already aware that the text can change upon blinking, we simply instructed them to read attentively and not search for changes proactively. During the tasks, participants were instructed to immediately speak up when they notice any change. After each task, we showed them each change that actually occurred in the corresponding text.

Results. In the second experiment, multiple changes per text were allowed; therefore, we were able to collect more data (that is, 73 changes) than in the first experiment (30 changes). None of the *Line-contained* changes in the *following* paragraph were noticed (Figure 4). For *Line-contained* changes in the *current* paragraph two out of 11 changes were noticed. Only one of the 10 *Inner paragraph* changes in the *following* paragraph was noticed, with four out of 11 changes being noticed if they happened in the *current* paragraph. *Outer paragraph* changes in the *following* paragraph were noticed in six out of 13 cases. *Outer paragraph* changes in the *current* paragraph were noticed eight out of 12 times. Furthermore, participants verbally reported not always noticing the screen flickering caused



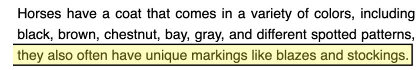
(a) A line-contained change: The word "special" is replaced with the word "unique".[1]

1. Web version of GIF: https://tinyurl.com/9348uh



(b) An inner paragraph change: A middle sentence is rephrased.[2]

2. Web version of GIF: https://tinyurl.com/9347uh



(c) An outer paragraph change: The last sentence is rephrased to be longer.[3]

3. Web version of GIF: https://tinyurl.com/9346uh

Figure 3: Examples for each change level. The yellow box in these examples are for illustration purposes only and they were not shown to the readers. If your PDF viewer does not support animations please use the provided links to view them in a browser.

by the overlay, supporting our hypothesis that changes are detected because the text updates only after blinking, due to a delay longer than the blink duration.

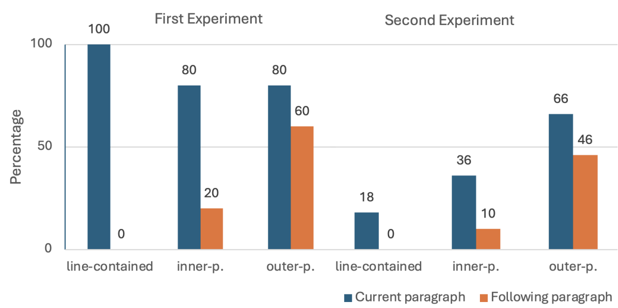


Figure 4: The percentage of changes noticed in the current and following paragraph during the first and second experiment.

5 Discussion and Limitations

The results of our experiments support our hypothesis that blink-induced change blindness can also be used in the context of reading. Although our preliminary experiments (with small sample size) do not allow us to draw definitive conclusions, the results indicate interesting findings that are worth exploring. Because no participant noticed any changes when they were *Line-contained* and at a distance of one paragraph, we assume that any changes farther away would also be unnoticeable. We observed interesting findings for *Line-contained* changes in the paragraphs currently read. In the first experiment, all five changes were noticeable, while in the second experiment, only two out of 11 changes were noticeable. This indicates the usefulness of the white overlay (in the second experiment), which guarantees that the changes can not be observed by the reader. In contrast to change blindness during saccadic eye movements, where only changes in capitalization were possible [14], we found that blink-induced change blindness allowed replacement of words and full sentences. With noticeability increasing sharply for the *Outer paragraph* changes, we further assume that participants were much more sensitive to positional changes in the outside structure of the paragraphs than to those occurring inside.

We noticed two technical limitations of our prototype. Namely, the accuracy of the gaze position was at times unreliable and the detection of blink events had some delay. Although the Pupil Core reportedly has an accuracy of up to 0.6 degrees, head movements of our participants inevitably affected the data quality. This led to situations where a blink triggered the change of an undesired part of the text. Recalibration and using a chin-rest to maintain a more fixed head position are frequently used, albeit strenuous techniques. Blinks last between 100 and 400 ms [21], but the eye is fully closed for only about 50 ms [12, 21]. *Incomplete* blinks [17], where the eyelid covers less than two-thirds of the cornea, may also occur. In our prototype, the blink detection algorithm only checks for pupil obstruction[4]. The algorithm correctly identifies *complete* blinks but is also triggered by *incomplete* blinks as long as the upper eyelid covers the pupil. Thus, our prototype does not distinguish between *incomplete* and *complete* blinks and does not determine the exact blink phase. Furthermore, since we are building on top of the Pupil Core processing pipeline with a latency of 45ms, blink-induced changes may occur too late, which additionally increase their noticeablity. In future studies, we plan to improve blink onset detection and differentiate between complete and incomplete blinks.

6 Conclusion

Our findings from two preliminary experiments demonstrate that blink-induced change blindness allows feasible real-time modification and augmentation of a text without the reader noticing. These findings encourage conducting systematic user experiments that may contribute to the development of useful features for reading assistants that exploit blink-induced change blindness to calmly support users.

In the future, we plan to improve our system and use contextual data to *personalize* text during blinks; such a tailored reading experience would utilize information such as the reader's eye movements that are synthesized with their reading preferences. Possible concrete applications include tools that help users learn a foreign language. Specifically, a personalized reading assistant would identify words that the user has difficulty in comprehending, and then modify the text to induce a better contextual understanding of the word's meaning. In fact, we envision a range of possibilities that stem from the real-time simplification or complexification of texts to create personalized learning and comprehension experiences.

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