PeriText: Utilizing Peripheral Vision for Reading Text on Augmented Reality Smart Glasses

Pin-Sung Ku*
Department of Computer Science and Information Engineering
National Taiwan University

Yi-Hao Peng †
Department of Computer Science and Information Engineering
National Taiwan University

Yu-Chih Lin ‡
Department of Computer Science and Information Engineering
National Taiwan University

Mike Y. Chen §
Department of Computer Science and Information Engineering
National Taiwan University

ABSTRACT

Augmented Reality (AR) provides real-time information by superimposing virtual information onto users' view of the real world. Our work is the first to explore how peripheral vision, instead of central vision, can be used to read text on AR and smart glasses. We present Peritext, a multiword reading interface using rapid serial visual presentation (RSVP). This enables users to observe the real world using central vision, while using peripheral vision to read virtual information. We first conducted a lab-based study to determine the effect of different text transformation by comparing reading efficiency among 3 capitalization schemes, 2 font faces, 2 text animation methods, and 3 different numbers of words for RSVP paradigm. We found that title case capitalization, sans-serif font and word-wise typewriter animation with multiword RSVP display resulted in better reading efficiency, which together formed our Peritext design. Another lab-based study followed, investigating the performance of the Peritext against control text, and the results showed significant better performance. Finally, we conducted a field study to collect user feedback while using Peritext in real-world walking scenarios, and all users reported a preference of 5°eccentricity over 8°.

Index Terms: Human-centered computing—Human computer interaction (HCI)—HCI design and evaluation methods—User studies; Human-centered computing—Visualization—Visualization design and evaluation methods Human-centered computing—Human computer interaction (HCI)—Interaction paradigms—Mixed/ augmented reality;

1 INTRODUCTION

Augmented Reality (AR) smart glasses provide the capability to superimpose virtual information onto views of the real world. Information about real-world objects and other sources of information, such as instant messages, can be seamlessly provided to enable users to interact with the real world while staying in touch with friends and families.

Prior work on AR have positioned information off-center to avoid occluding the center portion of users' field of view relative to users' faces [13, 17, 19, 27]. However, these approaches require the users' pupil to physically move off the primary focus to the side and use their central vision to view the information, causing safety concerns and social acceptance issues.

To design a better approach to display information, we need to have a better understanding of the human visual system [26]. Human vision can be categorized into central, para-central, and peripheral vision (See Fig. 2). The fovea provides central vision, which is the very center of gaze with an eccentricity of 2.5 (5 of the field of view), and has the highest visual acuity. Para-central vision has an eccentricity of 4, and the rest is peripheral vision, which can be up to more than 90. Peripheral vision is weaker at distinguishing detail, color, and shape, because the corresponding density of receptor and ganglion cells is lower and the representation in the visual cortex of the brain is much smaller. Therefore, unlike central vision, peripheral vision might respond differently to various text design.

Figure 1: PeriText is a multiword reading interface for peripheral vision on Augmented Reality smart glasses. While (left) users focus on tasks in the real world such as walking, (right) PeriText provides real-time text information using rapid serial visual presentation, with words sequentially displayed below their center gaze, represented by the red crosshair.

This paper explores using peripheral vision to read text, and proposes PeriText, a multiword reading interface using rapid serial visual presentation (RSVP) [20]. Our approach enables users to perceive features of high importance using central vision and simultaneously read text using peripheral vision. (See Fig. 1) We conducted two lab-based studies using display monitors with an eye-tracking system, and a field study using Microsoft Hololens [1], an AR head-mounted display, mounted with a mobile eye-tracking device.

Study 1 (N=14) aims to determine the effect of different text transformation in our peripheral vision area. We measured the reading efficiency under 34 different conditions, combinations of 6 text transformations, 2 retinal eccentricities, and 3 numbers of words displayed at a time for RSVP. Results showed that for both eccentricities, title case, sans-serif font, and word-wise typewriter effect result in higher accuracies when displayed multiple words at a time.

Study 2 (N=8) evaluated the performance difference between control text, where no transformation is applied, and PeriText interface, designed by combining factors derived from the previous study. Under both eccentricity settings (5°and 8°), PeriText resulted in 6% to 9% higher accuracy than the control text, and significance is found under 8 eccentricity by Bonferroni post-hoc testing.

---

[*] e-mail:scott20122@gmail.com
[†] e-mail:b03902097@ntu.edu.tw
[‡] e-mail:b01902044@ntu.edu.tw
[§] e-mail:mikechen@csie.ntu.edu.tw

Study 3 (N=8) collected both qualitative user feedback and NASA Task Load Index in real-world walking scenarios. We designed 2 different walking tasks, a heavy-loading one, where users needed to cross a street, and a light-loading one, where users walked on pedestrian-only walkway. Results showed that all users preferred 5 of eccentricity for our PeriText reading interface, and a significant difference in mental loading is found for 5°and 8°eccentricities under heavy-loading walking.

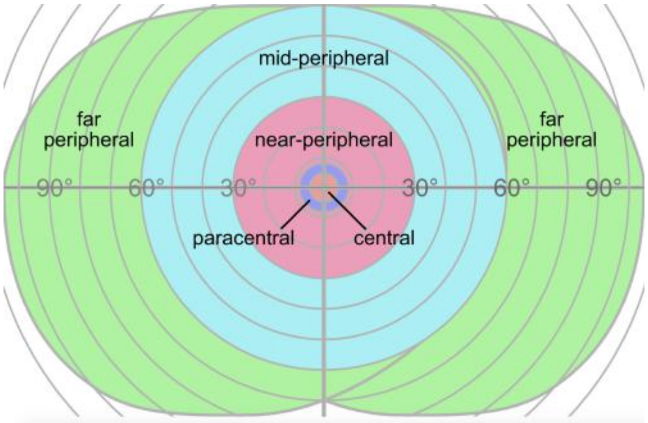

Figure 2: Field of View of the Human Eye. (from [28], CC BY-SA 3.0). The central vision is the very center of our gaze with an eccentricity of 2.5°, and para-central vision has an eccentricity of 4°. The rest is peripheral vision, which is weaker at distinguishing details and colors.

Our contribution includes the following: 1) The first to understand reading efficiency using peripheral vision under 34 different text transformation and display settings, including 3 capitalization schemes, 2 font faces, 2 animation methods and 3 numbers of words for RSVP. 2) We propose a multiword reading interface for peripheral vision using rapid serial visual presentation. 3) The first peripheral reading interface on AR smart glasses with in-the-field evaluation and user feedback.

The rest of the paper is organized as follows: we first discuss related work, then present the three user studies and analysis, and finally discuss and summarize our findings.

2 RELATED WORK

2.1 Reading with RSVP

Rapid Serial Visual Presentation (RSVP) is a concept introduced in the 1970s [20], where text is displayed word-by-word at a fixed location sequentially without blank frames. RSVP had been used as an effective reading method for limited screen space such as smart watches or optical see-through head-mounted display (HMD) devices. Dingler *et al.* investigated the reading control of RSVP paradigm on smart watches, comparing gaze interaction with direct touch [11]. In their study results, implicit pausing using eye tracking brought about a higher comprehension, as opposed to explicit pausing through users' direct touch. Rzayev *et al.* extended the use of RSVP paradigm to peripheral visual field and conducted a 24-participant study where 3 text positions are investigated for RSVP and line-by-line scrolling presentation under both sitting and walking situations [25]. However in their study, walking scenario was simple and without obstacles, and users could use their central vision for reading text.

Compared with the researches above, the RSVP text display we promoted is designed specifically for peripheral vision where visual acuity is much lower than that in central vision.

2.2 Imagery using Peripheral Vision

Peripheral visual field is outside the center of our gaze and takes up the largest portion of our vision. Bahna & Jacob used projected image to promote information transfer without adversely affecting users' comprehension and efficiency of the original reading task [7]. Luyten *et al.* explored human interaction with near-eye peripheral image displays, and found that simple, distinctive shapes have high recognition rates, which can be further improved with image motion, when users are given a limited set of possible shapes beforehand [15]. Jones *et al.* improved the precision of distance judgement and perceived scale of virtual environment with static peripheral stimulation [14]. Nakao & Knuze used LED dot pattern animations on the sides of smart glasses to display notifications modify traveling speeds as users walk wearing the glasses [18]. Also, peripheral vision has been leveraged to foster more immersive virtual worlds [24].

These researches exploited peripheral vision to transfer more information and provide symbolic notification; however, they did not focus on conveying text-based information. Chua *et al.* investigated nine display positions on a monocular optical see-through HMD with 3 types of notification: color, application icon, and text [9]. Still, as stated by the authors in their limitation, the experiment results cannot be generalized to all HMDs, such as binocular ones.

2.3 Peripheral Reading

Researchers in psychology and vision science have investigated reading using peripheral vision since the 1970s. Anstis S.M. looked at character recognition performance at different eccentricities [6]. Bernard *et al.* designed a font face specifically for peripheral vision to reduce character similarity [8]. However, they only tested the recognition accuracy at 6°eccentricity and didn't explore other text alterations, such as capitalization and animation. Chung *et al.* showed that font size and crowding effect, caused by showing multiple letters together, both affect reading speed [10]. Prior studies have shown the peripheral reading performance improves through training [12, 16].

Compared to prior work in peripheral reading, we propose a multiword reading interface after investigating peripheral reading under 34 different conditions and evaluated it on AR glasses in the field.

3 STUDY 1: READING EFFICIENCY

Study 1 aims to determine the effects of different text transformations on reading efficiency in the peripheral area. In this experiment, we defined and calculated the goodput as the number of words per minute perceived correctly by the user.

We recruited 14 participants (5 female, 9 male) between ages of 16 and 26 (mean=21.9, SD=2.1). All participants have normal or corrected-to-normal eyesight, and can read and speak English fluently.

3.1 Stimuli

We used sentences filtered from nine novels obtained from Project Gutenberg [2], same as those used in [10]. All sentences were short single sentences containing only the 5000 most frequent words in written English, according to word frequency tables from the Corpus of Contemporary American English (COCA) [5]. All sentences started with a capitalized character and contained no punctuation other than a period, and the period at the end of each sentence was removed during the experiment. These sentences had lengths ranging from 2 to 8 words (mean=4.26, SD=1.92), or 5 to 53 characters (mean=18.92, SD=9.35). The words had number of characters ranging from 1 to 13 (mean=3.67, SD=2.27).

We explored 6 text transformations: 2 adjusting capitalization (full capitalization, title case), 1 adjusting font (serif font), 2 with animations (character-wise typewriter effect, word-wise typewriter effect), and 1 control text with no transformation applied (regular capitalization, sans-serif, no animations). Fig. 3 shows the text positions and transformations we used in this study. We set serif, instead of sans-serif, as an independent variable because typical monitors display sans-serif, whereas serif fonts are more commonly seen on prints. Words in the serif transformation were rendered in Times New Roman font, while the sans-serif text was rendered in Helvetica font.

Each text transformation was displayed at 2 peripheral positions, one close to para-central vision (retinal eccentricities of 5) and the other further away in periphery (8), with 3 numbers of words (1 word, 2 words, and 3 words) displayed at a time for RSVP. The one-word control text is identical to the one-word word-wise typewriter effect for both text positions. Due to this overlap, there are 34 combinations instead of 36 in total.

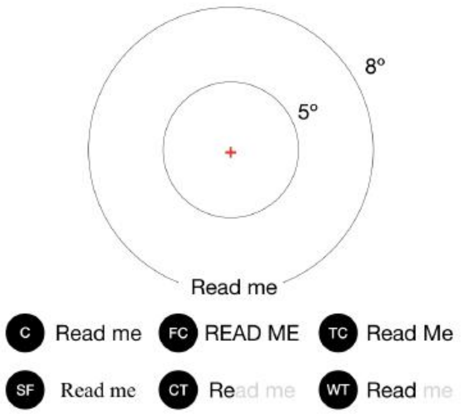

Figure 3: Text transformations and positions in Study 1. We investigated the performance of reading accuracy using peripheral vision with a total of 6 different text transformations: full capitalization (FC), title case (TC), serif font (SF), character-wise typewriter effect (CT), word-wise typewriter effect (WT), and control text without transformation (C). The 2 text positions are 5 and 8 retinal eccentricities. In addition, the number of words displayed at a time for RSVP paradigm is 1, 2, and 3.

3.2 Procedure

The participants were asked to sit at a distance of 60 cm from a 22-inch LCD monitor, which displayed black text with white background, as shown in Fig. 4.

To ensure that text was presented at the desired eccentricities, we monitored the observers fixation using Tobii EyeX [4], an eye-tracking device. The observer was asked to look towards a red crosshair, the fixation point, at the center field of view for 10 seconds. During the 10-second calibration, more than 450 sampled coordinates were retrieved for every participant. We would discard a trial if the number of eye position samples that were away from the mean of the calibration samples by two standard deviations exceeded 5% of the total number of samples. We also make sure that the inaccuracy produced by the eye-tracking device is far smaller than the distance of the criteria for discarding trials so that such error could be neglected. Overall approximately 14% of the trials were discarded and repeated throughout the entire study.

Each user had their individual 6 font sizes and speeds to be used for each of the 6 combination of text positions (ecc. 5 and 8) and number of words displayed at a time (1, 2, 3). All the participants went through a practice session to determine their font sizes and speeds. In the practice session, these 6 pairs of size and speed settings were retrieved where participants were able to recognize 80% of the words in 5 sentences displayed with no transformation. Note that for both the word-wise and character-wise typewriter transformation, the speed would be altered so that when compared to other text transformations, the same amount of text appeared within a certain time frame.

For each condition, there were 10 trials, *i.e.*, 10 sentences, resulting in a total of 340 sentences per participant. The participant was asked to read out what they saw or say ”can’t see it”. For the goodput value calculation, the period from showing the sentence to the participant reading it out was recorded, and the answers were typed into a text file immediately for further comparison. The eye-tracker started to record the eye positions for each trial at the beginning of a sentence and stopped recording right after the sentence was completed. The experiment order of the 6 text transformations was counter-balanced through a Latin Square.

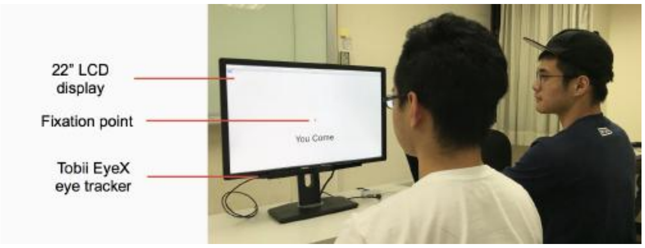

Figure 4: The experiment setup for user study 1 and 2. The participants sat at a distance of 60 cm from the 22-inch LCD monitor, and the text are displayed in the lower visual field. We told the participants to look towards the red crosshair in the middle and used Tobii EyeX eye tracker to ensure the fixation.

3.3 Results and Discussion

Participants were instructed to read out right after the RSVP finished without comprehending the sentence. For each condition, we added all the periods participants spent on a trial into a total period, and we compared the answers with the sentences to get the sum of correctly answered words. The formula of good put value is shown as follow:

$$G = \frac{W}{T} \tag{1}$$

where W is the total amount of words answered correctly in this condition, and T is the total period indicated by the unit of minutes. The goodput values are then calculated as the number of words correctly perceived by the participant per minute, *i.e.*, , in WPM as shown in Fig. 5.

3.3.1 Number of words displayed at a time

The average goodput values for displaying 2 and 3 words at a time are higher than one-word-at-a-time, under both eccentricities and all 6 transformations. ANOVA analysis showed significance under all 12 combinations of eccentricities and transformations, with p values ranging from 1e-14 to 5e-6.

3.3.2 Capitalization

Title case transformation performed better than both full capitalization and baseline, *i.e.*, control text. The goodput value of title case is 4.8% to 8.6% higher than that of control text. A possible explanation is that as text length increased, title case could have aided the user in determining both the beginning and the end of each word. In addition, ANOVA analysis found significant difference between title case and baseline for 5°eccentricity and displaying 2-word-at-a-time (F(1, 26) = 4.386, p = 0.045).

3.3.3 Serif / Sans-Serif

Serif font transformation always resulted in lower goodput values than baseline, which used sans-serif font. The differences range from 3.7% to 8.3% although ANOVA analysis did not show any significance. We thus decided to use sans-serif font in our PeriText.

3.3.4 Animation

The average goodput values using word-wise typewriter transformation are higher than both character-wise and control text under all multiword situations. The goodput values of word-wise typewriter effect can be up to 9.8% higher than those of control text, and as a result we use this animation in our interface design, although no significance is found by ANOVA.

	Baseline	Full Capitalization	Title Case	Serif Font	Character Typewriter	Word Typewriter
5º - 1-word	179.4	189.4	183.2	164.6	181.8	179.4
5º - 2-word	354.3	362.9	371.4	328.6	344.6	367.6
5º - 3-word	390.4	387.1	423.9	375.4	386.8	402.5
8º - 1-word	149.2	148.3	143.9	137.7	143.3	149.2
8º - 2-word	254.8	262.4	273.2	243.3	257.3	264.4
8º - 3-word	267.1	263.2	286.4	257.1	286.2	293.2

Figure 5: The average goodput values (in WPM) under 6 different text transformations, 2 eccentricities, and 3 numbers of words for RSVP paradigm. The goodput value is calculated as the number of words perceived correctly per minute. Green background indicates better performance than baseline, *i.e.*, , larger average goodput value.

4 STUDY 2: EVALUATE OUR PERITEXT DESIGN

According to the goodput results and analysis of study 1, we designed PeriText, our multiword reading interface for peripheral vision, to be 1) title case, 2) sans-serif, and with 3) animation of word-wise typewriter effect. In this lab study, we investigated the performance difference between PeriText and the control text. The PeriText design combines the transformation factors derived from the results of the previous study, while control text is where no transformations are applied.

We recruited 8 participants for this study, aging 23 in average (SD=1.07). All participants have normal or corrected-to-normal eyesight, and are able to read and speak English fluently. Seven of them also participated in Study 1.

4.1 Stimuli & Procedure

In this study, we use the same corpus, *i.e.*, sentences, as in Study 1. The text is displayed at 5°and 8°eccentricity for both control text and PeriText interface, resulting in a total of 4 conditions. The number of words displayed at a time for RSVP paradigm is set to 2 in this study because we found the average reading accuracy is higher than 3-word-at-a-time in the previous study.

The desktop monitor and eye-tracking system are set up in exactly the same way as they were in the previous study (Fig. 4), and the criterion for discarding trials is the same. The order of the 4 conditions is counter-balanced across participants using Latin Square. Each condition consists of 20 trials, *i.e.*, 20 sentences, resulting in a total of 80 sentences presented to each participant.

4.2 Results and Discussion

The average goodput values for all 4 conditions: 2 interface designs x 2 eccentricities are shown in Fig. 6. For both 5°and 8°eccentricities, the goodput values using PeriText are both higher than those of control text by 6.7% and 12.4%. In addition, ANOVA showed significant differences in goodput performance for both 5 (p=0.023) and 8 (p=0.019) eccentricities.

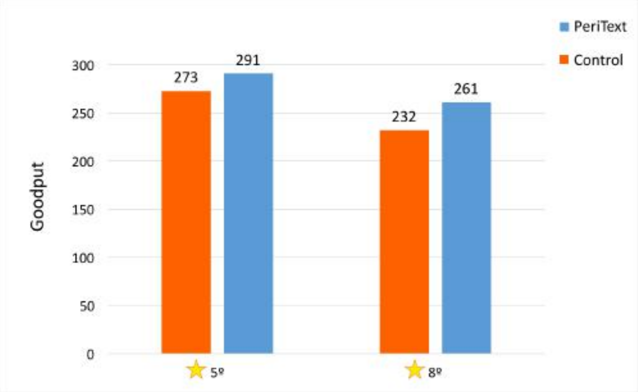

Figure 6: Goodput results of Study 2, comparing the performance of PeriText against control text. The goodput values are calculated as the average number of words perceived correctly per minute. PeriText resulted in 6.7% and 12.4% higher goodput values than control text, for both 5°and 8°eccentricities, and significance found through ANOVA.

5 STUDY 3: FIELD STUDY USING AR GLASSES

To understand how PeriText performs in real-world settings, we designed a field study where users wore AR glasses and walked around a university campus with 2 different levels of loadings. We collected qualitative user feedback and NASA-TLX index afterwards to understand user preference.

5.1 Stimuli

Similarly, the text stimuli we used in this study is sentences drawn from the same corpus as mentioned in the previous two studies. The text would be displayed at both 5°and 8°eccentricities below center fixation point, which is indicated by a red crosshair as in the previous studies, and the number of words displayed at a time using RSVP paradigm is also 2. With two walking tasks of different loading (1 heavy- and 1 light-loading) and two eccentricities (5°and 8°), we have four conditions for each participant. The experiment order of the four conditions is counter-balanced across all participants through a Latin Square. There would be 80 sentences in total for a participant, *i.e.*, 20 for each condition.

5.2 Participants

8 students (1 female, 7 male) ranging from age 22 to 26 (mean=23.5, SD=1.4) participated in this user study. All participants had normal or corrected-to-normal eyesight, and were fluent in speaking and reading English. Six of them participated in both the first and the second studies before.

5.3 Procedure

The participants were asked to put on Microsoft Hololens, a head-mounted display with eye-tracker by Pupil Labs [3] to detect the user's conscious and unconscious glances towards the peripheral text.

The field study had two walking tasks of different levels of loading. In the light-loading task, users walked on pedestrian-only walkways on the university campus and in the meantime read the text presented by PeriText. On the other hand, for heavy-loading walking task, users have to cross a street on campus where there would be bicycles and other vehicles. The participants were always accompanied by two experimenters all the time during the study for their safety.

During the experiment, the participant walked at their own pace and read out what they saw on the AR glasses, and was reminded to look at the red crosshair throughout the experiment. We discarded the trials using the same criterion as in the previous studies.

After user finished the 20 trials for each condition, we collected NASA-TLX index ratings, including the following 6 aspects: mental, physical, and temporal loading, as well as performance, effort, and frustration. Also, after all 4 experiment conditions are finished, we collected users' qualitative feedback.

5.4 Results and Discussion

5.4.1 Reading Performance

As shown in Fig. 7, the reading performance of reading at 5°eccentricity is better than reading at 8°. With ANOVA analysis and Bonferroni post-hoc tests, significant differences of goodput performance are found between the two eccentricities, under both light-loading (p=0.009) and heavy-loading (p=0.003).

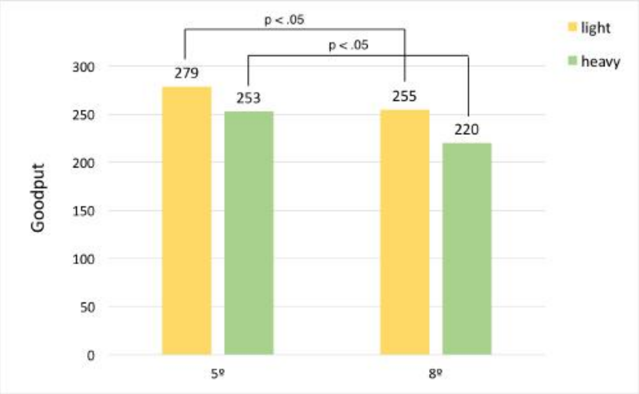

Figure 7: Reading performance when using PeriText in a real-world walking scenario under 4 conditions: 5°and 8°eccentricities x light-loading and heavy-loading tasks. The goodput values, averaged from all participants, are calculated as the number of words perceived correctly per minute, *i.e.*, in WPM. Significant difference is found between 5°and 8°of eccentricity, for both tasks.

5.4.2 NASA-TLX

Fig. 8 summarizes the average NASA Task Load Index reported by the participants. The effort required for reading at 5°is lower than reading at 8°eccentricity for both light-loading and heavy-loading conditions. The Kruskal-Wallis testing showed significant difference for three individual subscales: 1) mental loading, 2) physical loading, and 3) frustration ($p < .05$).

5.4.3 User Feedback

After participants finished the study, we asked them for feedback on their experience using PeriText. We also asked them about their preferred eccentricity.

Most participants had positive attitude towards reading on AR glasses. Six out of eight participants think they would use it, e.g., "Reading on those AR smart glasses provides a seamless experience to receive information" (P1) and "In the beginning I'm not used to the Hololens but later I soon got better. I think this might be the way people would live like several years after." (P5). There are also some different feedback on the Hololens and the reading interface as well. "I don't feel comfortable wearing AR glasses although it is really convenient. It was just too heavy." (P4)

All participants prefer displaying at 5°over 8°, e.g., "The text at 5°is clearer for me." (P4) and "8°would definitely take me both more time and more efforts to perceive the words." (P5). When further asked about the interference level, they don't think there existed a noticeable difference between the two positions. "They are both not annoying to me during the walking tasks." (P1) and "The text didn't interfere with my walking." (P8)

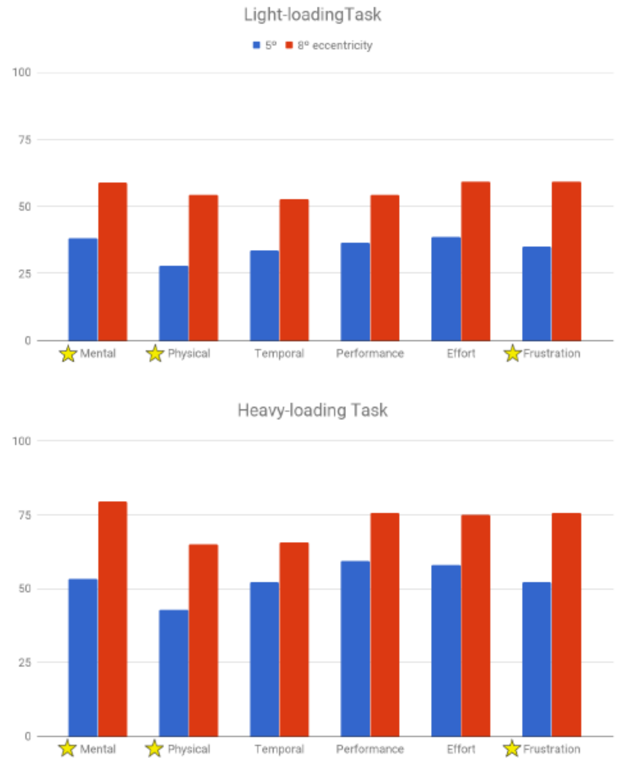

Figure 8: The average NASA-TLX scores from the field study. For both light-loading and heavy-loading tasks, the overall task load required for 5°eccentricity is lower than that for 8°. In addition, significantly lower ($p < .05$) scores found in three individual subscales: 1) mental, 2) physical, and 3) frustration.

6 LIMITATIONS AND FUTURE WORK

In this paper, we explored and compared 6 text transformations that experiment with capitalization, font, and animation. In order to determine the text form that maximizes reading efficiency in the peripheral area using RSVP paradigm on AR smart glasses, we would like to explore a greater variety of transformations such as bold text, scrolling text, or curved text.

Also, an investigation into the relationship between PeriText and various primary tasks is interesting and worthwhile, since what users are doing with their central vision might have influence on the reading performance of using PeriText.

During our study, each sentence was displayed once for each trial, and the goodput value was calculated without testing if the participants comprehended the whole sentences. However, several reading studies have shown that readers do not read sequentially, but re-visit text that was previously read, which is called back regressions [21–23]. In order to evaluate the actual reading speed, it is necessary to introduce such backward mechanisms into PeriText.

We have designed two real-world walking tasks with different levels of loading in our field study (Study 3). Other factors pertinent to the practicability of the multi-word reading interface, such as the amount of light and visual or body-movement distractions, should also be taken into consideration.

On the other hand, we would like to conduct more thorough experiments in the future to better understand how text transformation and display settings relate to social acceptance during daily interpersonal activities.

7 CONCLUSION

We presented the first study to investigate text-reading efficiency using peripheral vision on a monitor display, and experimented over 34 text forms, altering capitalization, font, and number of words displayed using RSVP. From our experiment, we discovered that the title case transformation and word-wise typewriter effect resulted in higher goodput when compared to other capitalization transformations and animations under multiword situations. Based on our experiment results, we propose PeriText, a multiword reading interface specifically designed for peripheral vision, combining title case transformation, sans-serif font, and the animation of word-wise typewriter effect. We evaluated the reading performance of PeriText against control text in the second lab study, and according to statistical analysis, significantly higher goodput is found when using PeriText. In the third study, we designed two real-world walking tasks, one light-loading and the other heavy-loading, where users walked around university campus wearing AR smart glasses. The results of this field study showed that users preferred displaying at 5 over 8°of eccentricity and they also performed significantly better at 5°no matter under the light-loading task or the heavy-loading one. Six out of the total 8 participants think of PeriText as a promising and interesting interface and would like to use it again in the future. Eye-tracking techniques are utilized in all 3 studies to ensure periphery of text display.

REFERENCES

[1] Microsoft hololens, https://www.microsoft.com/en-us/hololens.

[2] Project gutenberg, http://business.panasonic.com/pt-cw240u.html.

[3] Pupil labs - vr ar, soft hololens binocular add-on, https://pupil-labs.com/vr-ar/.

[4] Tobii eyex eye tracker, https://tobiigaming.com/product/tobii-eyex/.

[5] Word frequency data, corpus of contemporary american english, http://www.wordfrequency.info.

[6] S. M. Anstis. Letter: A chart demonstrating variations in acuity with retinal position. *Vision Res.*, 14(7):589–592, Jul 1974.

[7] E. Bahna and R. J. K. Jacob. Augmented reading: Presenting additional information without penalty. In *CHI '05 Extended Abstracts on Human Factors in Computing Systems*, CHI EA '05, pp. 1909–1912. ACM, New York, NY, USA, 2005. doi: 10.1145/1056808.1057054

[8] J.-B. Bernard, C. Aguilar, and E. Castet. A new font, specifically designed for peripheral vision, improves peripheral letter and word recognition, but not eye-mediated reading performance. *PLOS ONE*, 11(4):1–25, 04 2016. doi: 10.1371/journal.pone.0152506

[9] S. H. Chua, S. T. Perrault, D. J. C. Matthies, and S. Zhao. Positioning glass: Investigating display positions of monocular optical see-through head-mounted display. In *Proceedings of the Fourth International Symposium on Chinese CHI*, ChineseCHI2016, pp. 1:1–1:6. ACM, New York, NY, USA, 2016. doi: 10.1145/2948708.2948713

[10] S. T. Chung, J. Mansfield, and G. E. Legge. Psychophysics of reading. xviii. the effect of print size on reading speed in normal peripheral vision. *Vision Research*, 38(19):2949 – 2962, 1998. doi: 10.1016/S0042-6989(98)00072-8

[11] T. Dingler, R. Rzayev, V. Schwind, and N. Henze. Rsvp on the go: Implicit reading support on smart watches through eye tracking. In *Proceedings of the 2016 ACM International Symposium on Wearable Computers*, ISWC '16, pp. 116–119. ACM, New York, NY, USA, 2016. doi: 10.1145/2971763.2971794

[12] D. Fiset, F. Gosselin, C. Blais, and M. Arguin. Inducing letter-by-letter dyslexia in normal readers. *Journal of Cognitive Neuroscience*, 18(9):1466–1476, 2006.

[13] R. Häuslschmid, S. Osterwald, M. Lang, and A. Butz. Augmenting the driver's view with peripheral information on a windshield display. In *Proceedings of the 20th International Conference on Intelligent User Interfaces*, IUI '15, pp. 311–321. ACM, New York, NY, USA, 2015. doi: 10.1145/2678025.2701393

[14] J. A. Jones, J. E. Swan, and M. Bolas. Peripheral stimulation and its effect on perceived spatial scale in virtual environments. *IEEE Transactions on Visualization and Computer Graphics*, 19(4):701–710, 2013.

[15] K. Luyten, D. Degraen, G. Rovelo Ruiz, S. Coppers, and D. Vanacken. Hidden in plain sight: An exploration of a visual language for near-eye out-of-focus displays in the peripheral view. In *Proceedings of the 2016 CHI Conference on Human Factors in Computing Systems*, CHI '16, pp. 487–497. ACM, New York, NY, USA, 2016. doi: 10.1145/2858036.2858339

[16] M. Martelli, G. Di Filippo, D. Spinelli, and P. Zoccolotti. Crowding, reading, and developmental dyslexia. *Journal of Vision*, 9(4):14–14, 2009.

[17] M. Nakao, T. Terada, and M. Tsukamoto. An information presentation method for head mounted display considering surrounding environments. In *Proceedings of the 5th Augmented Human International Conference*, AH '14, pp. 47:1–47:8. ACM, New York, NY, USA, 2014. doi: 10.1145/2582051.2582098

[18] T. Nakuo and K. Kunze. Smart glasses with a peripheral vision display. In *Proceedings of the 2016 ACM International Joint Conference on Pervasive and Ubiquitous Computing: Adjunct*, UbiComp '16, pp. 341–344. ACM, New York, NY, USA, 2016. doi: 10.1145/2968219.2971393

[19] J. Orlosky, K. Kiyokawa, T. Toyama, and D. Sonntag. Halo content: Context-aware viewspace management for non-invasive augmented reality. In *Proceedings of the 20th International Conference on Intelligent User Interfaces*, IUI '15, pp. 369–373. ACM, New York, NY, USA, 2015. doi: 10.1145/2678025.2701375

[20] M. C. Potter. Short-term conceptual memory for pictures. *Journal of Experimental Psychology: Human Learning and Memory*, 2(5):509, 1976.

[21] K. Rayner. Eye movements in reading and information processing: 20 years of research. *Psychological bulletin*, 124 3:372–422, 1998.

[22] K. Rayner, B. R. Foorman, C. A. Perfetti, D. Pesetsky, and M. S. Seidenberg. How psychological science informs the teaching of reading. *Psychological Science in the Public Interest*, 2(2):31–74, 2001. PMID: 26151366. doi: 10.1111/1529-1006.00004

[23] K. Rayner, T. J. Slattery, and N. N. Belanger. Eye movements, the perceptual span, and reading speed. *Psychological bulletin*, 17(6):834–839, Dec 2010. doi: 10.3758/PBR.17.6.834

[24] G. Robertson, M. Czerwinski, and M. van Dantzich. Immersion in desktop virtual reality. In *Proceedings of the 10th Annual ACM Symposium on User Interface Software and Technology*, UIST '97, pp. 11–19. ACM, New York, NY, USA, 1997. doi: 10.1145/263407.263409

[25] R. Rzayev, P. W. Woźniak, T. Dingler, and N. Henze. Reading on smart glasses: The effect of text position, presentation type and walking. In *Proceedings of the 2018 CHI Conference on Human Factors in Computing Systems*, CHI '18, pp. 45:1–45:9. ACM, New York, NY, USA, 2018. doi: 10.1145/3173574.3173619

[26] H. Strasburger, I. Rentschler, and M. Jüttner. Peripheral vision and pattern recognition: a review. *Journal of vision*, 11 5:13, 2011.

[27] M. Tönnis and G. Klinker. Boundary conditions for information visualization with respect to the user's gaze. In *Proceedings of the 5th Augmented Human International Conference*, AH '14, pp. 44:1–44:8. ACM, New York, NY, USA, 2014. doi: 10.1145/2582051.2582095

[28] Zyxwv99. Field of view of the human eye, 2014. [License: CC BY-SA 3.0].