Perception of Peripheral Visual Cues in Augmented Reality during Walking: A Pilot Study

Anja K. FAULHABER, Ludger SCHMIDT

Fachgebiet Mensch-Maschine-Systemtechnik, Universität Kassel
Mönchebergstraße 7, D-34125 Kassel

Abstract. Augmented Reality (AR) glasses may be used in diverse mobile and multitasking contexts, for example, while walking. In such contexts, it is particularly important to display information without obscuring essential areas of central vision. Information can, thus, be presented to the peripheral vision. The objective of the present study was to investigate how peripheral visual cues should be displayed in AR to achieve efficient perception during walking. We conducted a pilot study and tested three different versions of directional cues presented while walking or standing still: simply popping up, moving towards the indicated direction, or changing color. The results indicated that the perception of peripheral cues in AR is generally less efficient while walking than standing still. Within the *walking* condition, the color-changing cue was perceived best.

Keywords: peripheral vision, directional cues, augmented reality, head-mounted displays

1. Introduction

Augmented Reality (AR) glasses are becoming more popular and might even replace smartphones in the future. They allow the superimposition of virtual information over the real world via see-through head-mounted displays. AR glasses can be used for various purposes in stationary contexts, such as while sitting or standing still. Additionally, they are particularly relevant for mobile contexts, for example, by providing navigational cues while the user is performing a primary task such as walking. In these mobile contexts, users may frequently experience safety-critical multitasking situations, e.g., in a road traffic scenario (Klose et al. 2019). It is, therefore, particularly important to display information in a way that allows efficient perception. Information displayed via AR glasses should not obscure essential areas of central vision, distract the user from the primary task, or impose additional cognitive demand on the user.

One potential solution for these issues is to present informational cues to the peripheral vision so that users do not need to look at the information directly and can stay focused on their primary task (Luyten et al. 2016). This is an option for AR glasses especially since new technologies increased the field of view so that visual cues can indeed be presented in the periphery. Nevertheless, the peripheral vision has certain capabilities and limitations that need to be taken into account when designing such informational cues (for a general overview see, e.g., Rosenholtz 2016). Several studies have started to investigate perceptional aspects of peripheral visual cues in the context of AR (e.g., Ishiguro & Rekimoto 2011, Sun & Varshney 2018). Further research in this area is required.

Peripheral vision plays an important role in the visual perception in motion and of moving objects (e.g., Luyten et al. 2016). A study suggested that peripheral visual stimuli are processed differently during walking (Cao & Händel 2019). In the context of AR, Rzayev et al. (2018) reported differences in the perception of peripheral information for a reading task during sitting and walking. Such differences might also apply to other visual stimuli, such as directional cues, but research in this area is still limited. Given that the mobile context of use is of particular relevance for AR glasses, the perception of peripheral cues during walking requires closer investigation.

The objective of the present pilot study was to investigate how directional cues presented to the peripheral vision should be displayed via AR glasses to achieve efficient perception both while standing still and during walking. The cues were displayed in three different versions developed based on a literature review. Further details on the study will be reported in the following.

2. Methods

2.1 Participants

The pilot study was conducted with six participants (one female, five male). Their ages ranged between 19 and 27 years with a mean of 23.7 years (SD = 3.2 years). Four of the participants wore contact lenses and none of them reported any color vision deficiencies. They participated voluntarily and did not receive payment.

2.2 Experiment Design

The pilot study was designed to test six conditions: three different versions of directional peripheral cues presented via AR glasses while the participants were either standing still or walking along a predefined track. The participants' task was to react to these cues by clicking the left or right button on a presenter dependent on the cue direction. The cues were blue triangles presented at a fixed position either in the top-left or in the top-right corner of the display, thereby indicating the respective direction. More precisely, these were equilateral triangles with a side length of 1.5 cm positioned at an eccentricity of 22.5° and at a distance of 94 cm. The triangles were displayed in the following three versions: 1) simply popping up as the baseline version, 2) moving continuously towards the indicated direction (based on findings by Luyten et al. 2016), or 3) changing color. In the latter case, a blue triangle was displayed in each corner permanently and one of them changed the color to green to indicate the direction. This version was chosen given that a study reported increased sensitivity to peripheral changes in contrast during walking (Cao & Händel 2019).

A within-subject design was used so that each participant completed all six experimental conditions. The order of the six conditions was counterbalanced across participants according to a Latin square design. In each condition, the cues were displayed 20 times - 10 cues indicating to the right and 10 cues to the left in random order. The time passing after a participant had reacted to a cue until the next cue appeared was randomized between 10 and 20 seconds.

Regarding the apparatus, the *Meta 2* AR glasses were used as they allow a 90° field of view. This is a relatively wide field of view as compared to other AR glasses currently available on the market and, thus, particularly suited for displaying peripheral visual cues. Unity was used for the implementation of the experiment.

We collected reaction times via clicks on the presenter. Moreover, participants were equipped with a pedometer in order to collect and analyze step frequencies. We assessed subjective workload ratings via the NASA Task Load Index (TLX, Hart & Staveland 1988) and analyzed errors. Following Cao & Händel (2019), we defined errors as clicks occurring after a reaction time threshold of one second. Moreover clicks on the wrong button and clicks when there was no cue displayed at all were also included as errors.

2.3 Procedure

Upon arrival, participants were informed about the study and their task. The experimenter pointed out that participants should not look directly at the peripheral cues. Instead they were asked to fixate a point marked on the wall when standing still or the centerline marking of the track during walking. Participants then filled in a demographic questionnaire and signed a consent form. The *Meta 2* was put on and calibrated and the participants received presenter and pedometer. Afterwards, the experiment started, which was divided into six blocks according to the six conditions. Within each block, the peripheral visual cues were presented in the respective version 20 times as described previously. The cues disappeared (or turned blue again in case of the color change version) as soon as the participants clicked the correct button on the presenter. After each block, participants completed the NASA TLX and at the end of the experiment, they were additionally asked to rank the cue versions. The experiment lasted about 100 minutes in total.

3. Results

For the data analysis, we conducted multiple Wilcoxon signed-rank tests with Bonferroni correction. We chose this test due to the small sample size and because the assumptions for parametric testing were not clearly met. However, none of the results reached statistical significance ($p > 0.05$). Therefore, only the descriptive statistics will be reported in the following to provide indications for potential follow-up studies with larger sample sizes.

First, average reaction times were analyzed and the results showed that participants generally reacted faster in the *standing still* condition (Figure 1, left). The median reaction times were below one second for all three cue versions. In the *walking* condition, on the other hand, the median reaction times increased considerably, particularly for the popping up and moving cues. In these cases, the data were also rather dispersed as indicated by the interquartile range (IQR). The color-changing cues led to the fastest reaction times within the *walking* condition and were with a median of 0.91 s even comparable to the results for the *standing still* condition. The median reaction times were the slowest out of all six conditions for the popping up cue presented while walking.

The NASA TLX scores were analyzed as indicators of subjective workload. More precisely, the composite raw TLX (RTLX) scores were used for analysis (Hart 2006). The results exhibited a similar pattern as the reaction times, given that workload trended generally higher in the *walking* condition (Figure 1, right). The color-changing cue received the lowest median RTLX score within the *walking* condition but the highest within the *standing still* condition. Again the popping up cue presented during walking led to the highest median RTLX score out of all six conditions.

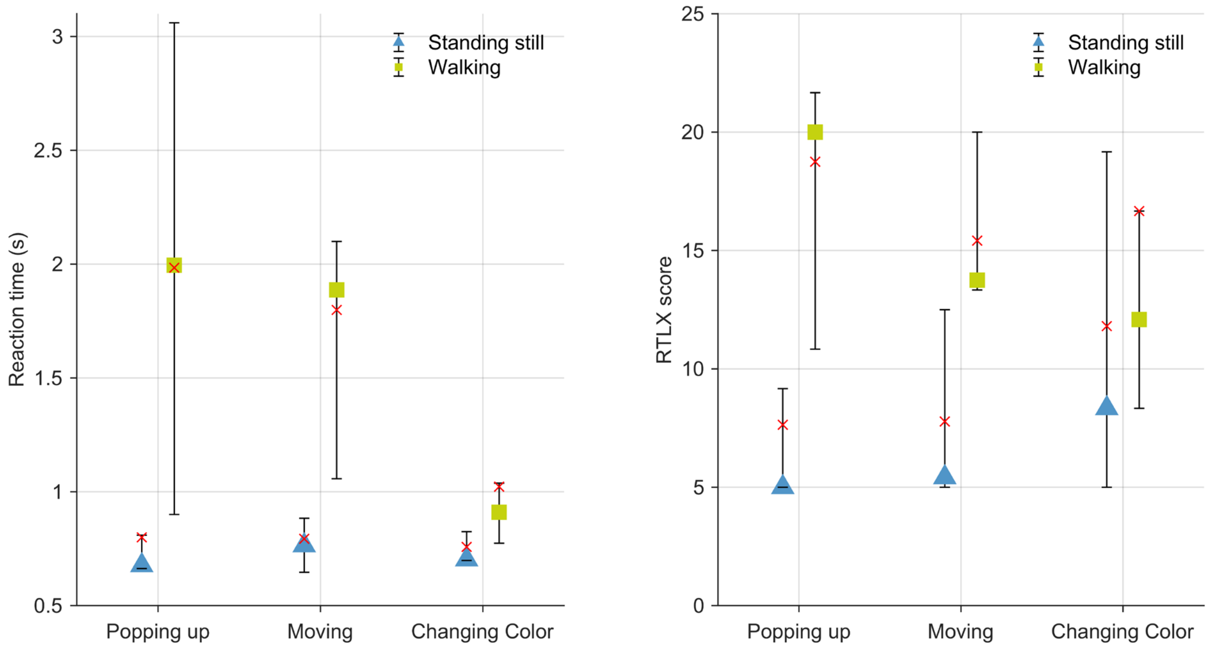

Figure 1. *Median reaction times in seconds on the left and median RTLX scores on the right for all six experimental conditions. The error bars show the IQR and the red crosses represent the respective mean values.*

The results from the error analysis indicated that 23.05% of all presenter clicks were errors according to the definition delineated above. The majority of errors occurred during walking with 18.66% and only 4.39% during standing still. Figure 2 shows the total number of errors across all participants for each condition. Participants tended to commit errors particularly in the *walking* condition for cues popping up and moving. With the color-changing cue, considerably fewer errors were committed. In the *standing still* condition, the total number of errors was at a similar level for all three cue versions.

The analysis of the step frequencies in the *walking* condition showed that the step frequency was the highest when cues were simply popping up (Mdn = 1.46, IQR = 0.13). This was followed by the cue changing color (Mdn = 1.44, IQR = 0.14) and the moving cue with the lowest step frequency (Mdn = 1.41, IQR = 0.07).

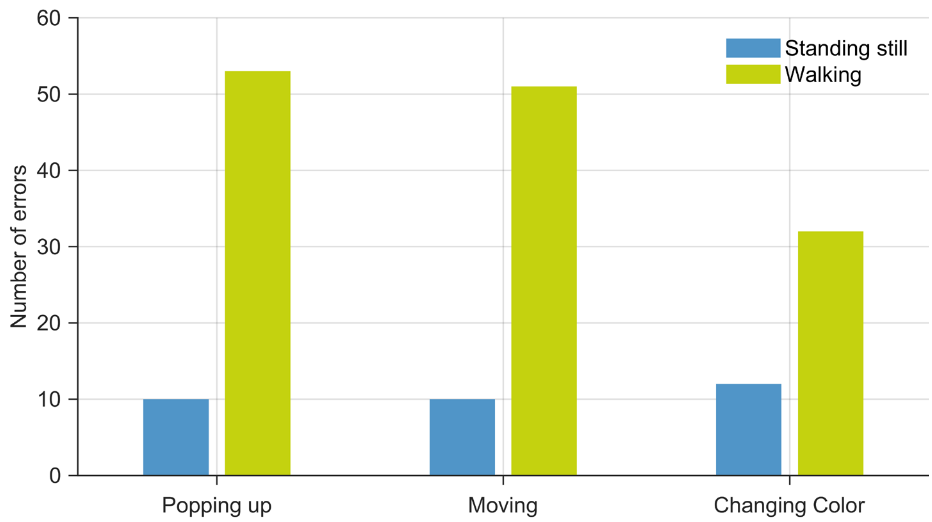

Figure 2. *Bar graph showing the total number of errors summed up for all participants in each one of the six conditions.*

Finally, the participants were asked to rank the cues separately for the *standing still* and for the *walking* condition to indicate which one of the three cue versions they preferred within the respective context. The results are presented in Table 1. For standing still, three participants favored the color-changing cue, two preferred the cue popping up, and only one chose the moving cue. For walking, four participants again ranked the color-changing cue first while two participants favored the cue popping up.

Table 1. *Results from the ranking of the cue versions by all six participants.*

Rank	Standing still			Walking		
	Popping up	**Moving**	**Changing color**	**Popping up**	**Moving**	**Changing color**
1	2	1	3	2	0	4
2	3	3	0	2	4	0
3	1	2	3	2	2	2

4. Discussion

The results of the present pilot study indicated that the perception of peripheral visual cues presented via AR glasses was in general more efficient when participants were standing still than when they were walking. Average reaction times were faster and workload ratings lower for all the cue versions presented when participants were standing still. Moreover, participants committed fewer errors. Within the *walking* condition, the results suggested a tendency towards a more efficient perception of the color-changing cue as compared to the ones popping up and moving. This was also reflected to a certain degree in the final ranking by the participants. Within the *standing still* condition, the differences between the three cue versions were rather small and no clear *favorite* could be identified.

Of course, the results reported here were obtained from a pilot study with only six participants. Due to the pilot character and the small sample size, the results did not reach statistical significance. Conducting a study with a larger sample would allow more powerful statistical tests and more robust results. Nevertheless, the results may serve to derive topics for future research.

Overall, the results can be interpreted in terms of the findings by Cao & Händel (2019). They reported that sensitivity to peripheral contrast changes increased during walking. This might explain the results for the color-changing cue and why it was preferred by the majority of participants in the *walking* condition. However, the results indicate that the perception of color-changing cues still tends to be less efficient in the *walking* condition as compared to *standing still*. This might be due to the dual-task situation when walking. Moreover, the triangle changed color from blue to green only once but a continuous change in color might be easier and faster to detect. This might not even require a change in color but a frequent flashing of the cue as a repetitive change in contrast might suffice (Vukotich et al. 2008). Further research is needed to shed light on this open issue.

Rzayev et al. (2018) suggested that meaningful motion of a cue is beneficial for the perception of information presented in the periphery. Our results indicate that the moving cue was, in fact, perceived more efficiently as compared to the baseline cue simply popping up. The difference observed was rather small, though, and could only be seen in the *walking* condition. Moreover, the reaction times in case of the moving cue were still considerably slower as compared to the color-changing cue. Future studies should investigate further whether cues with meaningful motion are in fact beneficial for perception.

Investigating the above mentioned open issues in future research may provide more insights into the adequate design of AR applications for mobile contexts of use. More precisely, future studies should be conducted based on the present results to inform the design of directional cues presented in the periphery via AR glasses during walking. This would be particularly relevant for application areas such as navigation systems.

5. References

Cao L, Händel B (2019) Walking enhances peripheral visual processing in humans. PLoS Biology 17(10):e3000511.

Hart SG (2006) Nasa-task load index (NASA-TLX); 20 years later. Proceedings of the Human Factors and Ergonomics Society Annual Meeting 50(9):904–908.

Hart SG, Staveland LE (1988) Development of NASA-TLX (Task Load Index): Results of empirical and theoretical research. In: Hancock PA, Meshkati N (eds) Human Mental Workload. Advances in Psychology, vol 52. Amsterdam: North Holland Press, 139–183.

Ishiguro Y, Rekimoto J (2011) Peripheral vision annotation: Noninterference information presentation method for mobile augmented reality. In: Inami M, Rekimoto J, Koike H, Saito H (eds) Proceedings of the 2nd Augmented Human International Conference (AH '11). New York NY: ACM, 1–5.

Klose EM, Mack NA, Hegenberg J, Schmidt L (2019) Text presentation for augmented reality applications in dual-task situations. In: 2019 IEEE Conference on Virtual Reality and 3D User Interfaces (VR). IEEE, 636–644.

Luyten K, Degraen D, Rovelo Ruiz G, Coppers S, Vanacken D (2016) Hidden in plain sight: An exploration of a visual language for near-eye out-of-focus displays in the peripheral view. In: Kaye J, Druin A, Lampe C, Morris D, Hourcade JP (eds) Proceedings of the 2016 CHI Conference on Human Factors in Computing Systems. New York NY: ACM, 487–497.

Rosenholtz R (2016) Capabilities and limitations of peripheral vision. Annual Review of Vision Science 2:437–457.

Rzayev R, Woźniak PW, Dingler T, Henze N (2018) Reading on smart glasses: The effect of text position, presentation type and walking. In: Mandryk R, Hancock M, Perry M, Cox A (eds) Proceedings of the 2018 CHI Conference on Human Factors in Computing Systems (CHI '18). New York NY: ACM, 1–9.

Sun X, Varshney A (2018) Investigating perception time in the far peripheral vision for virtual and augmented reality. In: Proceedings of the 15th ACM Symposium on Applied Perception (SAP '18). New York NY: ACM, 13.

Vukotich A, Popken M, Andrej A, Lübcke M (2008) Fahrerassistenzsysteme. ATZ Extra 13(2):170–177.

Acknowledgments. The authors wish to thank Mirko Kümmel for his help in implementing the experimental setup and conducting the experiments. This work was funded by the German Federal Ministry of Education and Research, funding code 16SV8241.

Gesellschaft für
Arbeitswissenschaft e.V.

Arbeit HUMAINE gestalten

67. Kongress der
Gesellschaft für Arbeitswissenschaft

Lehrstuhl Wirtschaftspsychologie (WiPs)
Ruhr-Universität Bochum

Institut für Arbeitswissenschaft (IAW)
Ruhr-Universität Bochum

3. - 5. März 2021

GfA-Press

Bericht zum 67. Arbeitswissenschaftlichen Kongress vom 3. - 5. März 2021

Lehrstuhl Wirtschaftspsychologie, Ruhr-Universität Bochum
Institut für Arbeitswissenschaft, Ruhr-Universität Bochum

Herausgegeben von der Gesellschaft für Arbeitswissenschaft e.V.
Dortmund: GfA-Press, 2021
ISBN 978-3-936804-29-4

NE: Gesellschaft für Arbeitswissenschaft: Jahresdokumentation

Als Manuskript zusammengestellt. Diese Jahresdokumentation ist nur in der Geschäftsstelle erhältlich.

Schriftleitung: Matthias Jäger
im Auftrag der Gesellschaft für Arbeitswissenschaft e.V.

Screen design und Umsetzung
© 2021 fröse multimedia, Frank Fröse
office@internetkundenservice.de · www.internetkundenservice.de