Paracentral and near-peripheral visualizations: Towards attention-maintaining secondary information presentation on OHMDs during in-person social interactions

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ABSTRACT

Optical see-through Head-Mounted Displays (OST HMDs, OHMDs) are known to facilitate situational awareness while accessing secondary information. However, information displayed on OHMDs can cause attention shifts, which distract users from natural social interactions. We hypothesize that information displayed in paracentral and near-peripheral vision can be better perceived while the user is maintaining eye contact during face-to-face conversations. Leveraging this idea, we designed a circular progress bar to provide progress updates in paracentral and near-peripheral vision. We compared it with textual and linear progress bars under two conversation settings: a simulated one with a digital conversation partner and a realistic one with a real partner. Results show that a circular progress bar can effectively reduce notification distractions without losing eye contact and is more preferred by users. Our findings highlight the potential of utilizing the paracentral and near-peripheral vision for secondary information presentation on OHMDs.

CCS CONCEPTS

• **Human-centered computing** → *Mixed / augmented reality*; *Information visualization*; Mobile devices.

KEYWORDS

paracentral, near-peripheral, social interaction, conversation, circular progress, reminder notification, interruption, HMD, smart glasses

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1 INTRODUCTION

The emerging mobile platform, optical see-through head-mounted displays (OST HMDs, OHMDs, Augmented reality (AR) smart glasses) allow just-in-time information assistance anywhere, at any time [16, 18, 34]. However, receiving information on OHMDs could distract users from their primary tasks [23, 26]. If the primary task involves social interaction, the appearance of unrelated secondary information (such as notifications) can be highly undesirable, as it negatively affects the quality of conversations and reduces eye-contact [20, 26].

To mitigate such negative effects during social interactions, past work has investigated various approaches, including using different modalities [6, 30], information bandwidth [30], display properties [36], and presentation timing [30, 40]. While these approaches are all helpful, one challenging problem remains unsolved: how to minimize the distraction of secondary information while users' attention is focused on the primary viewing target, especially in social conversational settings? One promising approach proposed in the literature is to distribute the secondary information to a different part of our eyes: instead of projecting the information to one's central vision, one can utilize the peripheral vision to perceive the secondary information, relieving the central vision to remain focused on the primary visual target.

Researchers investigating this approach in different multitasking scenarios have shown favourable results [7, 11, 17, 21, 24, 28, 32], for example, Chaturvedi et al. [4] has shown that by presenting visual cues to one's mid or far peripheral vision, one can reduce the usage of the central vision by as much as 50% under certain scenarios, thus allowing the central vision to be more focused on the primary visual target. However, one drawback of this approach is that the

capability of our mid and far peripheral vision is limited. While it is good at detecting motion, it is weaker at distinguishing details [35, 39]; thus, relying on it to perceive more precise information accurately can be challenging.

Built upon the previous approach of distributing secondary information to different parts of our eyes, we investigate two regions of our visual systems that are previously underexplored: the paracentral and near-peripheral vision, and explore secondary information visualization design that takes advantage of their unique capabilities. We design the circular progress bar, linear progress bar, and text labels and display them to the paracentral and near-peripheral regions of the eyes using an OHMD. In a series of two studies, we compared these design alternatives in a simulated and a realistic conversational setting, and the results indicate that the circular progress bar, designed to resemble the shape of our paracentral and near-peripheral region of the eyes, can better utilize their capabilities, thus allowing users to more effectively perceive secondary progress updates with minimum distraction to their primary viewing task. Our studies also reveal exciting insights that can guide the future design of attention-maintaining secondary visualizations for OHMDs, such as providing notification summarization, trip status, etc.

The contributions of this paper are thus the following: 1) a novel design for OHMD progress notifications to utilize paracentral and near-peripheral vision; 2) an evaluation of the proposed design, with two common designs in a simulated and realistic setting to understand the trade-offs between receiving notifications and quality of social interactions, based on which we discuss the potential OHMD designs to utilize the paracentral and near-peripheral vision for other multitasking situations.

2 RELATED WORK

The human's information needs and inclination towards staying connected via multiple digital sources and platforms have increased significantly in the past decade, and multitasking has become the go-to method for keeping up with today's fast-paced society [2, 37, 42].

With OHMDs, there is an increasing opportunity to attend to multiple sources of information. Depending on its compatibility and design, the secondary information can either enhance or distract the primary task. In social interaction scenario like face-to-face conversation, if the secondary information is closely related to the conversation, such as conversation cues [26, 44] or topics' suggestions [29], it can enhance social interaction. However, most secondary information in the form of notifications is not related to the current conversation. Their appearance can negatively affect the quality of conversations and reduce eye contact [20, 26].

To mitigate the potential distraction caused by secondary information displayed on OHMDs, researchers have conducted multiple studies and proposed several innovative solutions. We classified these studies under the following categories with an emphasis on social interaction scenarios:

Presentation modality: Multiple studies [6, 30] have been conducted to compare audio and visual modalities for secondary information delivery, and the consensus is that the visual modality is more suitable for secondary information delivery during social interactions because the information presented in auditory channels can cause more distraction to the conversation [30], and multiple auditory information presented at once can overlap with each other which makes it harder to distinguish [6]. Hence, in our paper, we explored design solutions in the visual modality.

Display properties of OHMD: Several studies investigated factors related to how the information is displayed on OHMD, such as its position and alignment, and its impact on reducing distractions [5, 19, 36]. Chua et al. [5] investigated how different positions of OHMD affected the noticeability and perception of notifications during multitasking. They recommended using middle-right, top-center, or top-right positions when users engage in multitasking situations where primary tasks require central vision. Rzayev et al. [36], studied the differences between displaying information in different alignments (observer-locked vs. receiver-locked) and positions (middle vs. top right), and their impacts on social engagement. Their investigations found that observer-locked alignment (i.e., information displayed at a fixed location relative to the observer/conversation partner) is generally perceived as less intrusive. We adapted the top-center position and observer-locked alignment in our design.

Organization and timing of the presented information: Various studies have investigated how the organization and timing of the secondary information affect the primary task. For example, Ofek et al.'s study [30] has found that participants are less affected when visual information comes in small batches and is delivered during gaps of speaking. Similarly, Tanveer et al. [40] tested delivering speech-related feedback continuously and sparsely in a public speaking scenario and found that sparse feedback was preferred. Inspired by these works, we piloted two kinds of *persistence* for information presentation, *continuous* and *intermittent* and used *intermittent* in our design.

Distribute information to different regions of the eyes: The last category of investigation looks into presenting information to different regions of the eyes to minimize potential distractions. Eyesight can be divided into two regions: the central and peripheral vision, where the central vision (a.k.a., foveal vision) is located in the very center of our gaze with an eccentricity (i.e., "angular distance from the center of the visual field or from the foveola of the retina" [27], also referred to as "visual angle" [12]) of 2.5°, and peripheral vision is outside of the central vision [21, 39]. Central vision has the best visual acuity and is heavily relied upon to perceive information [22].

However, peripheral vision is also capable of perceiving certain information. Offloading visual tasks to the peripheral vision can effectively reduce the reliance on and distraction to the central vision. In fact, a number of previous studies have explored this idea to support different multitasking scenarios [4, 7, 11, 17, 21, 24, 28, 32]. For example, Chaturvedi et al. [4] has shown that by presenting visual cues to one's peripheral vision, one can reduce the usage of the central vision by as much as 50% under certain scenarios. However, the capability of peripheral vision is limited. While it's good at detecting motion, it is weaker at distinguishing details [35, 39]; thus, relying on it to perceive more accurate information can be challenging.

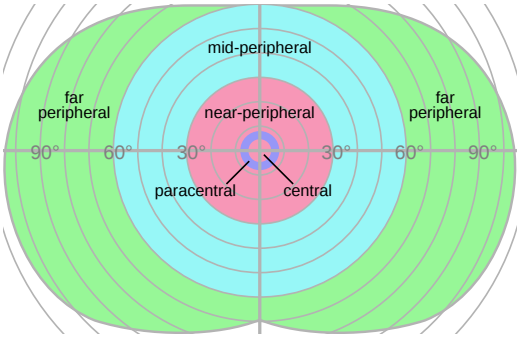

Figure 1: Angular Field of View of the Human Eye (source: [45] CC BY-SA 3.0). The central vision has an eccentricity (visual angle) of 2.5°, the paracentral vision has an eccentricity of 4°, and the near-peripheral vision has an eccentricity of 15°.

A closer look at the peripheral vision reveals multiple ring-shaped regions based on the eyes' anatomy. As shown in Figure 1, these regions are called paracentral, near-peripheral, mid-peripheral, and far-peripheral vision [4, 21, 39]. Among these regions, the mid-peripheral and far-peripheral have been explored in HCI for secondary information presentation (e.g., [4, 7, 11, 24, 28, 32]), yet the paracentral and near-peripheral regions (e.g., [21]) are underexplored. In this paper, we are interested in exploring the potential of paracentral and near-peripheral vision as they are shown to have more capabilities than other peripheral regions.

Although the literature has not reached a consensus on the exact location of paracentral region [39], multiple resources [4, 21] have indicated that paracentral vision is located between eccentricities (visual angles) of 2.5° and 4°, and the near-peripheral vision is located between eccentricities of 4° and 15°. Previous research [33, 38] has shown that people can recognize text using paracentral vision to a certain extent, based on the phenomenon called the 'parafoveal preview', though not as well as if the central vision was utilized. In addition, users' reading efficiency based on this parafoveal preview depends on their familiarity with the word, as they tend to guess the word based on context, especially if the word is common and familiar [38]. The near-peripheral region is capable of recognizing shapes and symbols [17, 31, Ch C.9]. Such capability may be further explored to perceive secondary information that requires more detailed displays than peripheral vision can handle, creating new opportunities for supporting visual multitasking. To explore this area, we selected three types of stimuli that can accommodate paracentral and near-peripheral vision: circular, linear, and text. We compared how these presentation types in these visual regions can influence the secondary information perception and primary task engagement in the following studies.

3 STUDY OVERVIEW

To test the potential of utilizing paracentral and near-peripheral vision for perceiving secondary information during social interactions (e.g., face-to-face conversations), we used three types of progress bars (Figure 2, Figure 4) to indicate time information: circular progress bar (*circular bar*), linear progress bar (*linear bar*), and text progress label (*text label*). We adopted suggestions from previous literature and tested (using 6 participants in an informal pilot study on a conversation setting) various positions, colors, lengths , sizes, thicknesses, etc., before finalizing the design (that minimized distraction to conversations yet allowed to obtain progress values comfortably) as follows:

The *text label* displays progress in numerical format (0% to 100%), which most accurately presents progress quantity. As reading facial expressions and maintaining eye contact are essential aspects of social interactions [1, 15], *text label* is placed just above the conversation partner's head to avoid visual overlaps between the progress display and face of the partner. This location falls within the paracentral and near-peripheral vision (the exact position of the gaze fixation determines which of the two vision types is utilized).

The *circular bar* progresses clockwise, beginning with 0% and ending with 100% at the 12 o'clock position. It has a ring shape that falls within the natural viewing region of our eyes, and fits into the paracentral and near-peripheral vision. As the average head height (i.e., the vertical distance from the bottom of the chin to the top of the head) is ≈ 26 cm in 95^{th} percentile [31, Ch B.8], the *circular bar* has a 30 cm outer ring diameter, and is 1 cm thick.

The *linear bar* progresses from left (0%) to right (100%). It is straight and horizontally placed, stretching over the two vision types. It is also put just above the head with a thickness of 1 cm and a length of 40 cm.

Since blue is visible in both the central and peripheral vision [4], we used the blue color (#FF0000FF in hex) to show the completed progress, and grey color (#FF6B6B6B) to show the incomplete one for *circular bar* and *linear bar*. The *text label* is shown in sans-serif font following Debernardis et al. [8] with a text height of 4 cm. All the progress bars are shown with the *observer-locked* alignment following Rzayav et al. [36]. The progress bars were placed at the same focal distance (depth) as the conversational partner (i.e., digital character in *study 1* and *non-wearer* in *study 2*) to avoid unnecessary focus switching.

There are trade-offs to using the three progress bar types; although *text label* indicates an exact quantity, previous literature has shown that the near-peripheral vision is less effective with recognizing text compared to shapes and symbols. *Circular bar* and *linear bar* are graphical in nature and thus easier to recognize via in paracentral and near-peripheral vision. The areas on screen that these three progress types occupy affects its noticeability and distractability - as size increases, the noticeability increases though it may become more distracting. The level of familiarity (users are more familiar with *linear bar*), may also influence the perception of progress information.

To formally investigate these design trade-offs regarding how it affects users' ability to perceive secondary information while focusing on the primary visual target, we conducted two studies. *Study 1* (sec 4) simulated the conversational setting with a digital character. The simulated setting was chosen to eliminate potential confounding factors that tend to accompany real-world scenarios, allowing us to establish stronger causal relationships between stimuli and dependent measures. To verify the external validity of study 1's results, we also conducted *study 2* using a realistic conversation setting.

We seek to answer the following research questions with our studies:

(1) How does the presentation style/type of secondary information on OHMDs impact perception of progress reminders (measured in terms of interpretive accuracy) during face-to-face conversations?
(2) How does the presentation style/type of secondary information on OHMDs impact the quality of face-to-face conversations?
   - Specifically, is circular progress visualization less distracting (measured in terms of gaze shifts away from the primary visual target) compared to linear progress visualization and text?

4 STUDY 1: OBTAINING PROGRESS INFORMATION WHILE MAINTAINING EYE CONTACT

Study 1 focuses on how different progress types influence participants' ability to maintain eye contact and acquire progress information. To avoid eye-tracking inaccuracies caused by the head movement of the conversation partner, we used a simulated face-to-face conversation setting to measure eye contact where participants focused on the facial features of a digital character.

4.1 Participants

12 volunteers (7 females, mean age = 22.7 years, SD = 3.1) from the university community participated in the study. They had normal or corrected visual acuity with no color deficiencies. 4 of the participants had prior experience using OHMDs for less than 3 hours. Each participant was compensated USD 7.25/h for their time.

4.2 Apparatus

Participants wore the Microsoft HoloLens2 [1] (FoV = 52° diagonal, resolution = 1440x936 per eye, refresh rate = 60Hz, eye-tracking with 1.5-3° accuracy at 30Hz) as the OHMD platform . The progress display program was implemented using Unity and MRTK [2] for HoloLens2 and Python.

The digital character (a muted talking head video extracted and resized from the original video by docstoc TV [9]) was displayed on a 27" LCD monitor (refresh rate = 60 Hz, resolution = 1920 x 1080 px) at eye level (see Figure 2). The progress bars were aligned w.r.t. digital character using fixed spatial coordinates.

The size of the face of the digital character was modeled after an average adult male (head height = 26 cm). To help participants maintain eye contact with the video, we enabled a gaze cursor (i.e., a white color dot) that dynamically follows participants' gaze movements and instructed participants to keep their gaze within a circular target region outlined in green color (see Figure 2). We ensured that the facial features of the digital character always stay within the target region for accurate eye-tracking.

The distance between the participant and the digital character was kept at 1.5 m (Figure 4), which falls within the common distance (1.2m - 3.6m) of natural social interactions defined by Hall [13, 36]. We also followed the HoloLens design guidelines [3] to avoid discomfort.

The diameter of the target region (i.e., green circle shown in Figure 4) was set to 13 cm covering the eyes and lips so that the visual angle, at a 1.5 m distance, falls into central vision (eccentricity/visual angle of 2.5°). The circular bar falls into the paracentral vision if a participant is focusing on the edges of the target region like the digital character's eyes (angle 3.2°), and falls into the near-peripheral vision if a participant is focusing on the center of the target region like the digital character's nose (angle 5.7°).

4.3 Task and Procedure

The study was conducted in a quiet room with indoor lighting conditions to provide a consistent user experience. Once entering the room, participants were briefed about the study process and signed the consent form. They were also familiarized with the OHMD and three types of progress bars, and the eye-tracking was calibrated. During the experiment, they were told to maintain their eye contact with the facial features of the digital character, even when the progress notifications appeared.

The three conditions of progress types were counterbalanced using Latin Square in a within-subject manner. For each condition, there were 15 trials. At each trial, a presentation type was assigned, and progress values (randomly chosen from 1-10, 20-30, ..., 90-100 bins with equal probability) were shown on the OHMD while participants focused on the digital character, which persisted on screen for 7 seconds. Progress bars appeared for 1 second at a random time between 2nd and 5th seconds (these numbers were chosen based on participants' ability to identify shown progress while maintaining eye contact, explored in a short pilot). Once the digital character disappeared, participants were instructed to mark the progress value they saw with pen and paper (Figure 2). They then proceeded to the subsequent trial after a 3-second break.

At the end of each condition, they filled out a questionnaire about their experience during that condition. Two-minute breaks were given between conditions to reduce fatigue. The entire experiment, including the post-questionnaire and interview, lasted for approximately 50-60 minutes per participant.

4.4 Hypotheses

As the circular bar is situated around the partner's face, it likely allows users to perceive the progress with less attention shifting than the linear bar. Additionally, circular bar and linear bar would be easier to perceive in the periphery due to their graphical nature over text label which may need central vision. Yet, the text label can provide precise quantitative information (e.g., 59%). Thus, we hypothesized:

H1: Text label enables progress information to be received more accurately over the circular bar and linear bar
H2: Circular bar is less distracting and cognitively less demanding than the linear bar and text label

4.4.1 Measures.

Following our RQs, we measured progress perception and quality of simulated conversation through both objective and subjective measures.

[1] https://www.microsoft.com/en-us/hololens/hardware
[2] https://github.com/Microsoft/MixedRealityToolkit-Unity
[3] https://docs.microsoft.com/en-us/windows/mixed-reality/comfort

Figure 2: (a) The participants' view of the digital character and circular bar through OHMD, (b) the linear bar and text label as viewed by the participant, (c) visual angles when focused on the target focal region and the circular bar. Depending on the focus location, the visual angles vary, making the progress bar visible from near-peripheral to paracentral vision, (d) the progress marking sheet given to participants. Original source of digital character by docstocTV [9].

Progress perception: For progress perception, we used progress recognition accuracy (Progress Accuracy = $1 - avg(|progress_{displayed} - progress_{marked}|)$, progress values were shown in percentage) as the objective measure (higher the better). We also collected subjective measures: Noticeability (`It was easy to notice the progress bar'), Perceived Ease of Identification (`It was easy to identify the progress shown in progress bar'), and Comfortability (`It was comfortable to check the progress while focusing on the face') using 7-point Likert scales (1 = Strongly Disagree, 7 = Strongly Agree).

Quality of the (simulated) conversation: For the quality of the conversation, we used Degree of distraction (Degree of Distraction = 1 - average percentage of times user's gaze is within the target region) as the objective measure (lower the better). We also collected the perceived task load for maintaining eye-contact and receiving progress information using Raw TLX (RTLX, [14]) and Perceived Interruption (`How much interruption did the progress bar cause to maintain eye contact when attempting to identify the progress?', 0-100 scale) as subjective measures.

4.5 Results

During the study, each participant completed 3 testing conditions with 45 total trials. A total of 540 (= 12 x 3 x 15) data points were collected. Figure 3a (Appendix A.1, Table 2) indicates participants' mean performance related to progress perception while Figure 3b (Appendix A.1, Table 3) indicates the mean performance related to quality of conversation.

4.5.1 Analysis. We applied a one-way repeated measures ANOVA or Friedman test (when in violation of the ANOVA assumptions) on the quantitative data. We tested normality and sphericity using the Shapiro-Wilk test and Mauchly test, respectively. We used multiple means of comparisons with Bonferroni correction as post-hoc tests for the parametric data and pair-wise Wilcoxon signed-rank tests with Bonferroni correction as post-hoc tests for non-parametric data. When non-parametric distributions could take a large range of values (e.g., RTLX, which ranged from 0-100) and followed parametric assumptions, we used the parametric tests. As for the interview recordings, we transcribed and thematically analyzed them.

4.5.2 Task Feedback. During the study, all participants focused on either the eyes, nose, nostrils, or mouth of the digital character based on their conversation habits. All participants found that focusing on the target region presented at the center of the digital character's face and marking the progress were *quite easy*. They also found that the shown progress bars were obvious when directly looked at. The majority of participants found that progress indicated duration was sufficient. Four participants preferred to have more time for the text label and mentioned that even with more time, they might not be able to recognize the text when focused on the face. Moreover, during post-interview, all participants found that the gaze cursor helped maintain focus on the target region and did not affect recognizing the progress values.

4.5.3 Progress perception. Figure 3a (Appendix A.1, Table 2) represents the summary of the measures.

Objective measure - Progress Accuracy

Overall, when participants maintained eye contact, the accuracy of progress identification dropped significantly for text label (MIN = 68.2; MAX = 99.8) compared to circular bar (MIN = 90.2; MAX = 98.3) or linear bar (MIN = 83.5; MAX = 98.1). The Friedman test revealed a significant effect ($\chi^2_{12} = 10.167$, $p = 0.006$, $W = 0.618$) of type. Surprisingly, post-hoc analysis revealed the circular bar was significantly higher ($p_{bonf} < 0.05$) than the linear bar and text label in terms of Progress Accuracy.

Notably, text label had the highest variation in average accuracy as participants' estimation error was either very high or very low. All participants found it *very difficult* to recognize and to distinguish digits as they looked *blurry* or *hazy* when not looking at them directly. Specifically, they found *curved* numbers (e.g., 3, 6, 8, 9) were harder to recognize than *pointy* ones (e.g., 1, 4). Yet, 2 participants could get almost full accuracy for text label while focusing on the face, indicating that there are individual differences in terms of ability to read text in paracentral vision. Similarly, a few participants found that the extreme ends of linear bar which were