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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CHI '22, April 29-May 5, 2022, New Orleans, LA, USA

ACM ISBN 978-1-4503-9157-3/22/04.
https://doi.org/10.1145/3491102.3502127

ACM Reference Format:
Nuwan Janaka, Chloe Haigh, Hyeongcheol Kim, Shan Zhang, and Shengdong Zhao. 2022. Paracentral and near-peripheral visualizations: Towards attention-maintaining secondary information presentation on OHMDs during in-person social interactions. In *CHI Conference on Human Factors in Computing Systems (CHI '22), April 29-May 5, 2022, New Orleans, LA, USA.* ACM, New York, NY, USA, 14 pages. https://doi.org/10.1145/3491102.3502127

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.

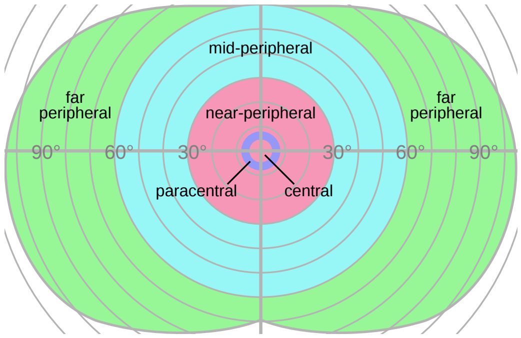


Figure 1: Angular Field of View of the Human Eye (source: [45] CC BY-SA 3.0). The central vision has an eccentricity (visual angle) of 2.5°, the paracentral vision has an eccentricity of 4°, and the near-peripheral vision has an eccentricity of 15°.

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 *type*s 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 docstocTV [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 2^{nd} and 5^{th} 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

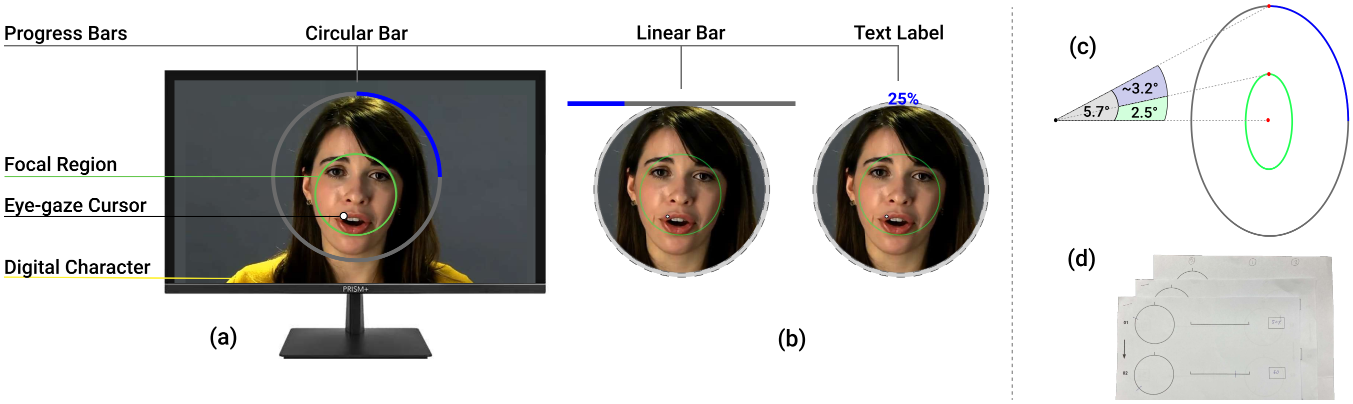


Figure 2: (a) The participants' view of the digital character and *circular bar* through OHMD, (b) the *linear bar* and *text label* as viewed by the participant, (c) visual angles when focused on the target focal region and the *circular bar*. Depending on the focus location, the visual angles vary, 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.

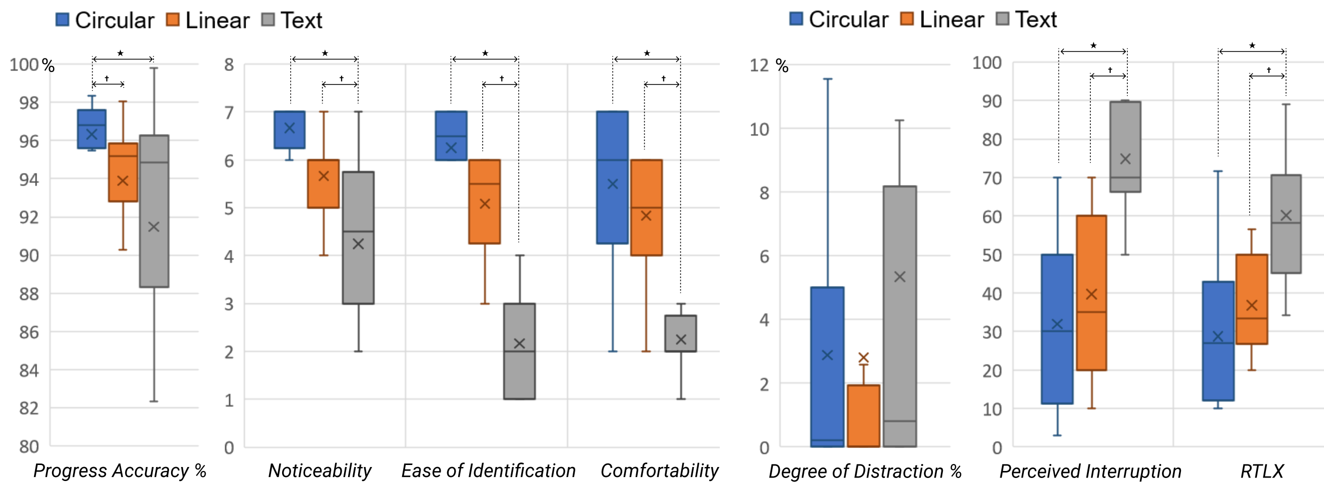
4.5.2 Task Feedback. During the study, all participants focused on either the eyes, nose, nostrils, or mouth of the digital character based on their conversation habits. All participants found that focusing on the target region presented at the center of the digital character's face and marking the progress 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 ($\chi^2(2) = 10.167$, $p = 0.006$, 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



(a) Progress perception **(b) Quality of conversation**

Figure 3: Measures in simulated conversation setting (N = 12). $\star$ and † represent significant (p < 0.05) post-hoc tests and $\times$ inside box plot represents the mean value point. See Appendix A.1, Table 2 and Table 3 for details.

further away from central vision were harder to read. In contrast, most participants perceived that the *circular bar* was easier to recognize the position correctly as it was larger and had an additional element of "angle", e.g., 25% is at a 90° angle from the center, which made the progress position more obvious.

Subjective measures - Noticeability, Ease of Identification, and Comfortability:

Circular bar had the highest average ratings for *Noticeability*, *Ease of Identification*, and *Comfortability*. Friedman tests revealed significant effects of *Noticeability* ($\chi^2(2) = 14.6$, $p < 0.001$, W = 0.388), *Ease of Identification* ($\chi^2(2) = 21.56$, $p < 0.001$, W = 0.307), and *Comfortability* ($\chi^2(2) = 16.13$, $p < 0.001$, W = 0.578). Post-hoc analyses revealed that *circular bar* was significantly different (higher, $p_{bonf} < 0.05$) from both *linear bar* and *text label* in terms of *Noticeability*. Similarly *text label* was significantly different (lower, $p_{bonf} < 0.05$) than *linear bar* and *circular bar* in terms of *Ease of Identification* and *Comfortability*.

The majority (10/12) of participants mentioned that the *circular bar* appearing around the face with a larger area was more noticeable than the *text label* or *linear bar*, which made it easier for them to identify the progress.

4.5.4 Quality of conversation. Figure 3b (Appendix A.1, Table 3) represents the summary of the measures.

Objective measure - Degree of Distraction:

Even though there was no significant difference ($\chi^2(2) = 3.257$, $p = 0.196$, W = 0.703) between progress *types*, *text label* had the highest average value for *Degree of Distraction*.

Subjective measures - Perceived Interruption and RTLX:

Overall, *circular bar* had the lowest *Perceived Interruption* and *RTLX*. Repeated-measures ANOVAs revealed significant effects of *Perceived Interruption* ($F_{2,22} = 21.026$, $p < 0.001$, $\eta^2 = 0.657$) and *RTLX* ($F_{2,22} = 16.646$, $p < 0.001$, $\eta^2 = 0.602$). Post-hoc analyses revealed *text label* was significantly different (higher, $p_{bonf} < 0.01$) than *linear bar* and *circular bar* in terms of *Perceived Interruption* and *RTLX*. Results for individual indices of *RTLX* are given in Appendix A.2.

Moreover, all participants ranked *text label* as the most distracting *type*, as it was difficult to read or "figure out" numbers in the periphery and prompted most of them to shift their focus away from the face. The majority of participants (10/12) chose *circular bar* as the least distracting as it enabled them to perceive progress notifications without disruptions in focus.

4.5.5 Preference. The majority of participants (10/12) ranked *circular bar* as their most preferred progress type while *text label* was the least preferred. In our interview, participants reported that the surrounding shape of the *circular bar* enabled them to identify the shown progress without moving their gaze and thus was more comfortable to look at while maintaining eye contact. In addition, the *circular bar* resembled the familiar "clock" with progress shown at an "angle". Given the larger size, they were able to perceive the progress notifications with greater accuracy.

The remaining participants (2/12) who chose the *linear bar* as the preferred option reported that the fixed location of the *linear bar* enabled them to track progress values more easily than the *circular bar* progress values could appear in any location around the face.

All participants choose the *text label* as the least preferred option, as the *text label* was "difficult to decipher" (distinguish digits) and participants needed to put more effort into interpreting the numbers (in paracentral and near-peripheral vision) while keeping their gaze on the face.

4.6 Discussion

Surprisingly, there is evidence against *H1* (i.e., *text label* enables higher accuracy) as the *circular bar* had significantly higher *Progress Accuracy* and *Ease of Identification* than the *text label*. Text can only be clearly perceived when presented within central vision [17, 33], and this was not the case for our *text label* condition.

Given that both *circular bar* and *linear bar* have simpler visual patterns than *text* [43, Ch 6], and shapes and colors have a higher recognition angle than text [17, 31, Ch C.9], the *circular bar* and *linear bar* were easier to recognize in paracentral and near-peripheral vision than the *text label*.

As expected, results showed that the *circular bar* had significantly lower *Perceived Interruption*, *RTLX*, and a lower *Degree of Distraction* than the *text label*, thus partially supporting *H2* (i.e., *circular bar* leads to less distraction than *linear bar* and *text label*). We lack the evidence to conclude the same for the *circular bar* and *linear bar* comparison.

Comparing the *text label* with the *circular bar*, we find that there is a trade-off between accuracy and maintaining (uninterrupted) eye contact for the *text label*. A majority (83%) of participants preferred the *circular bar*, and this is in keeping with the results that showed *circular bar* yielded the lowest distraction levels, as well as highest accuracy while participants maintained uninterrupted eye contact. Hence, the *circular bar* is the ideal choice for presenting progress/task completion reminders than when users need to maintain their focus on a primary visual target.

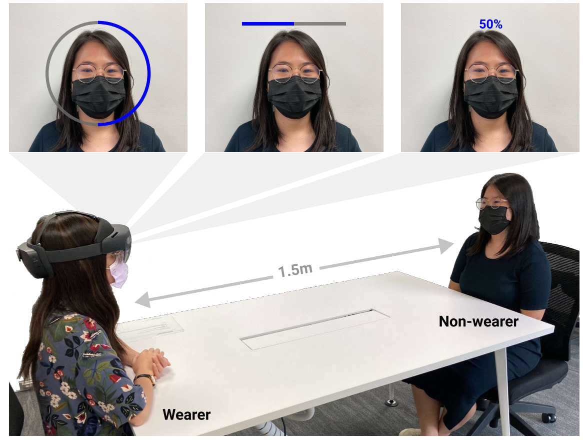


Figure 4: The *wearer* is wearing the OHMD while engaging in a conversation with the *non-wearer*. The *wearer* sees three progress *types* in three conditions. From left to right, the top figure depicts the progress bars from left to right: *circular bar*, *linear bar*, and *text label*.

5 STUDY 2: IDENTIFY HOW THE PRESENTATION TYPE OF PROGRESS NOTIFICATIONS AFFECT FACE-TO-FACE CONVERSATIONS

In this study, we complemented *study 1* with a more realistic setting where a pair of participants (*wearer* and *non-wearer*, see sec 5.1) engaged in a conversation. We first explored the best form of *persistence* (i.e., whether progress is presented *continuous*ly or *intermittent*ly on the OHMD) for progress bar design through a pilot study with 4 participants, and subsequently conducted a formal study with 12 participants.

5.1 Apparatus

As shown in Figure 4, the same HoloLens2 was used by the *wearer*, where the progress information was displayed at an observer-locked alignment with the face of the *non-wearer*. The observer-locked alignment was implemented using Windows' FaceTracker[4] API and Unity's viewport to world mapping[5] at a fixed distance with a tracking rate of 10Hz. To minimize the misalignments of progress bars with respect to *non-wearer* due to tracking errors, we asked the trained *non-wearer*s to limit their *sudden* head movements during conversations. For realistic effects, the gaze cursor was removed as they are rarely used in real conversations. The distance between *wearer* and *non-wearer* was kept at 1.5 m, replicating *study 1*.

5.2 Tasks

A *wearer* and *non-wearer* pair engaged in face-to-face conversation on a given topic (Figure 4) provided by a researcher. The topics were selected from the CAE speaking test [10] (e.g., "What are the advantages and disadvantages of shopping by a computer?") similar to Mayer et al. [25] and Rzayev et al. [36]. We limited each conversation session to be 6 minutes so that participants had sufficient time to engage with conversation and attend to progress notifications.

Apart from engaging in the conversation as the primary task, both the *wearer* and the *non-wearer* had secondary tasks. To simulate a real progress indicator, we asked the *wearer* to end the conversation smoothly when the progress bar reached 100% and stand up. The *non-wearer* was instructed to observe whether the *wearer* paid attention to the conversation and rate the eye contact and naturalness of the conversation after the conversation. None of them knew the secondary task of each other.

5.3 Progress bar design

5.3.1 General design. In order to establish the conversation flow, we start the progress bar from 0% after 30 seconds when the conversation starts. Then the progress bars increment in an uniform speed of 1% every 3 seconds, and reach 100% in 5 minutes. After that, the progress bar stays on the view for additional 45 seconds before it informs the *wearer* to stop the session.

5.3.2 Pilot study to determine the persistence. We tested two kinds of *persistence*: *continuous* and *intermittent* for progress notification presentation. The *continuous* progress bar stays on the screen and the *intermittent* progress bar only appears when the progress value reaches multiples of 10% (i.e., 10%, 20% ...), and stays on the screen for 3 seconds when appears. The appearance interval and staying duration were fixed from a few pilots.

The pilot result with 4 participants showed that *continuous persistence* on screen is perceived as more distracting and is less preferred compared with *intermittent*. For distraction, participants reported that they tended to "constantly check the progress" as the value was continuously changing, and they did not intend to do so especially when they had more time left for conversation. This constant

[4] https://docs.microsoft.com/en-us/uwp/api/Windows.Media.FaceAnalysis.FaceTracker
[5] https://docs.unity3d.com/ScriptReference/Camera.ViewportToWorldPoint.html

checking broke their "train of thoughts". For preference, most participants (3/4) preferred *intermittent* as it highlighted the progress with minimal distraction. This finding is aligned with the literature [30, 40] that recommends sparse feedback to reduce distraction from the primary task during multitasking. The only participant who reported more distraction from the *continuous* still preferred it due to the accurate time tracking. Based on the pilot result, we decided to only use the *intermittent persistence* in the formal study.

5.4 Participants

The *wearers* were 12 participants (7 females, mean age = 22.4, SD = 2.5) recruited from the university community with the same standard as *study 1* (sec 4.1). The *non-wearers* were 2 volunteers recruited from the same community (2 males, mean age = 24.5) and were instructed to manage the conversation so that it would continue fluidly. They were fluent in English and trained as conversation partners. The *non-wearers* were kept blind to the study conditions. None of them participated in study 1.

5.5 Procedure

The study was conducted in a quiet room under indoor lighting conditions to provide a consistent user experience. Once *wearers* arrived, they were briefed about the study process and signed the consent. They would also get familiar with the OHMD and the three types of progress bars. They were also informed about the intermittent appearance, expected duration and frequency of the progress bar during the conversation. They were reminded to focus on the conversation while attending to the progress bars.

When the *wearer* was confident in the setup, the *non-wearer* was guided to the same room, and seated on the opposite side of a table (see Figure 4) such that they were 1.5 m apart from each other. They were given a practice topic to engage in a conversation without any progress bar displayed on the OHMD for 3-4 minutes. Then they engaged in three conversation sessions with three progress types. After each conversation, the *wearer* removed the OHMD and the participant pair filled the questionnaires (sec 5.6.2) separately. A 2-minute break was given after completing the questionnaire before proceeding to the next condition. At the end, both participants filled a questionnaire on the overall experience and separately attended the semi-structured interview sessions. The interview captured the *wearer*'s perception of progress indication, experience of receiving progress notifications and the *non-wearer*'s perception of conversation. The study took approximately 80 minutes per participant pair.

5.6 Study Design

Three conditions: the *circular bar*, *linear bar*, and *text label* were tested with a within-subject design and fully counterbalanced.

5.6.1 *Hypotheses.*

Based on *study 1's* results, we hypothesized;

- *H3*: The *circular bar* enables increased attention to the social interaction over the *linear bar* and *text label*
- *H4*: The *circular bar* is preferred over the *linear bar* and *text label*

5.6.2 *Measures.*

In this study, we collected the subjective measures of *wearer*'s perception towards the different progress *types*, and the quality of the two-way conversation. At the end of the study, we also collected the *wearers*' preference for different progress types.

Progress perception: Similar to *study 1*, the perception of the progress bar was evaluated using *Noticeability* and *Comfortability* by the *wearers* after each condition. Additionally, they evaluated *Perceived Effectiveness* in delivering the current progress with a 7-point Likert scale (1 = Very Ineffective, 7 = Very Effective).

Quality of the conversation: To measure quality of the conversation, we employed three categories of measures: attention and concentration, eye contact, and naturalness; from both the *wearer*'s ([W]) and *non-wearer*'s ([N]) perspectives. These measures were adapted from McAtamney et al.'s study [26], except the 5-point Likert Scales were changed to the 7-point (1 = Strongly Disagree, 7 = Strongly Agree) to increase the sensitivity and to be consistent with other measures (see Table 1 for the list of measures used in the study).

5.7 Results

During the study, each participant completed three conditions resulting in a total of 36 (= 3 x 12) conversations. Figure 5 (Appendix B.1, Table 4) and Figure 6 (Appendix B.1, Table 5) represent the summary of measures.

5.7.1 *Progress perception.*

The post-hoc analysis showed that *circular bar* had the highest *Noticeability* and *Perceived Effectiveness* compared with the *linear bar* and *text label*, and a higher *Comfortability* compared with the *text label*. The Friedman test revealed significant differences between progress *types* in terms of *Noticeability* ($\chi^2(2) = 8.600$, $p = 0.014$, W = 0.580), *Comfortability* ($\chi^2(2) = 6.324$, $p = 0.042$, W = 0.515), and *Perceived Effectiveness* ($\chi^2(2) = 8.424$, $p = 0.015$, W = 0.696). The differences between *circular bar* and *linear bar* in terms of *Noticeability* and *Perceived Effectiveness* were significant ($p_{bonf} < 0.05$), where the difference in terms of *Comfortability* was not significant ($p_{bonf} = 0.098$). The detailed results are summarized in Figure 5 (Appendix B.1, Table 4).

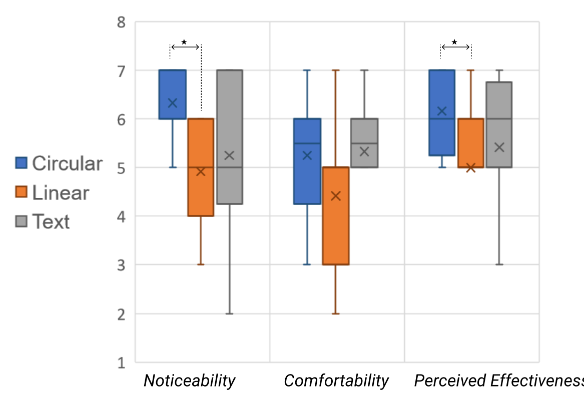


Figure 5: Perceived rating on progress *types* by *wearer* (N = 12). ⋆ represents significant ($p < 0.05$) post-hoc tests and × inside box plot represents the mean value point. See Appendix B.1, Table 4 for details.

Table 1: Aspects and measures on conversation behavior of *wearer* from the *wearer* [W] and the *non-wearer* [N] point of views (source: [26]).

Aspect on conversation	Measures
Attention and concentration	**AC1**: [W] 'When the other person was speaking, I was always listening to them' / [N] 'When I was speaking, I think the other person was always listening to me' **AC2**: [W] 'I was always concentrating on the conversation' / [N] 'I think the other person was always concentrating on the conversation'
Eye contact	**EC1**: [W] 'When I was speaking, my attention was towards the other person' / [N] 'When the other person was speaking their attention was towards me' **EC2**: [N] 'When I was speaking the other person maintained eye contact'
Natural behavior	**NB1**: [W] 'I acted naturally at all times during the conversation' /[N] 'The other person acted naturally at all times during the conversation' **NB2**: [W] 'I felt relaxed during the conversation'/ [N] ' The other person appeared relaxed during the conversation'

During the interview, all *wearer*s mentioned that although they needed "a short time" to glance at the progress bars, they did not have to look away from their partner for the *circular bar* condition. However, for the *text label* and *linear bar*, they needed to look to the top of the screen to check the progress. While they could still maintain eye contact with the *non-wearer*, a few *wearers* (4/12) acknowledged that the sudden appearance of progress bars distracted them from their conversations. This distraction was relatively subtle as the progress bars did not block their view of the *non-wearer* and only appeared intermittently. But they felt the time-pressure when the progress reaches the end.

5.7.2 Quality of the conversation.
We analyzed the subjective ratings of attention and concentration (AC), eye contact (EC), and natural behavior (NB), from both the *wearer*'s ([W]) and *non-wearer*'s ([N]) perspectives. There was a significant difference on *NB2* from the *wearer*'s perspective (Friedman test, $\chi^2(2) = 10.563$, $p = 0.005$, W = 0.781), yet *text label* ($M = 4.67$, $SD = 1.56$) was not significantly lower than *circular bar* ($M = 5.50$, $SD = 0.91$, $p_{bonf} = 0.096$) and *linear bar* ($M = 5.67$, $SD = 0.78$, $p_{bonf} = 0.063$). Besides this measure, there were no significant differences for other measures. The detailed results are summarized in Figure 6 (Appendix B.1, Table 5).

At the start, the *non-wearers* felt "uncomfortable" and "awkward" to talk with *wearer*s who were wearing "bulky" OHMDs but eventually felt it more natural after conversation started. They mentioned that using "spectacle-like" OHMDs in a casual conversation would be socially acceptable as it would similar to the use of smartphones when engaged in a conversation, but still "rude" in a professional setting. This could be the reason that Microsoft Hololens2 is still too bulky and does not look like regular glasses. We expect this problem to be mitigated with more lightweight and natural looking glasses such as the North Focals[6] smart glasses.

From the *non-wearer*'s point of view, they did not notice any major differences of the naturalness of conversation among sessions. Sometimes, they noticed that *wearers*' eyesight "moved to the corner", it was still perceived as natural because they assumed the *wearer*s were thinking.

5.7.3 Wearers' preference. As shown in Figure 7, more than half of the participants (7/12) ranked *circular bar* as their highest preference, while 3 participants ranked *text label* and 2 participants ranked *linear bar* as their most preferred.

During the interview, participants who preferred *circular bar* reported that it was easier to notice. The surrounding shape and the clock-like design enabled them to easily recognize the progress while maintaining attention on their partners. Compared with *circular bar*, the *linear bar* required them to shift their attention away from the partner to see the progress. The *text label* was even harder to notice, required more attention to read the text, and was perceived as more "stressful" as it provided exact numbers.

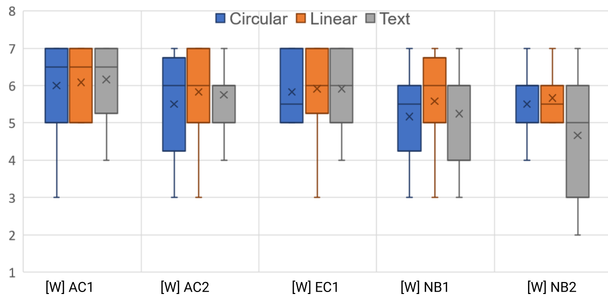
However, some participants did not prefer *circular bar*, mentioning that the progress position of the *circular bar* move around the face, so they needed more time to check where to look. The *text label* and *linear bar* were in a relatively fixed position so they only needed to focus on one area to read progress.

Non-wearers' perception of wearers' eye contact: Observers didn't detect much differences in eye-contact among the different conditions, although they did notice sometimes the participant looking up, or to the side, but took this to mean "they were processing what was said" or "thinking about what to say next" but did not take this as a lack of eye contact. As the linear bar was placed above the head, when the *wearer* looked at it, this could have been mistaken for thinking, but overall, this behavior did not cause any discomfort to *non-wearer*s.

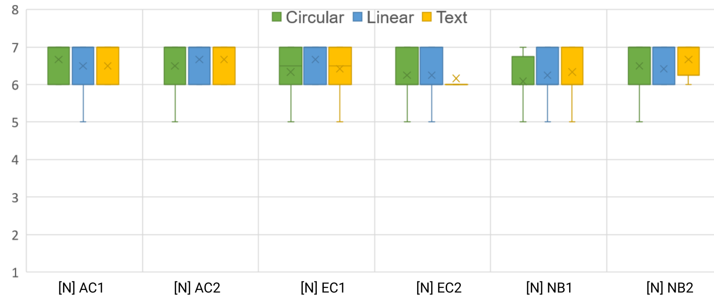
5.8 Discussion

Overall, the majority (7/12) of *wearer*s chose *circular bar* as their first preference, which is consistent with *study 1*, thus *H4* (i.e., *circular bar* is preferred over *linear bar* and *text label*) is validated in a more realistic context. In accordance with *study 1*, this study showed the *circular bar* had higher noticeability and comfortability, and was also perceived as most effective in delivering progress information.

[6] https://www.theverge.com/2019/2/14/18223593/focals-smart-glasses-north-review-specs-features-price



(a) Perceived ratings by *wearer* [W]



(b) Perceived ratings by *non-wearer* [N]

Figure 6: Perceived rating on progress *types* by *wearer* [W] and *non-wearer* [N] (N = 12). × inside box plot represents the mean value point. See Appendix B.1, Table 5 for details.

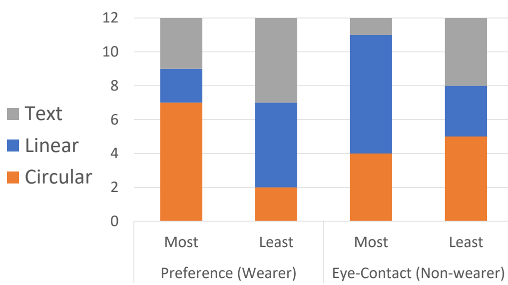


Figure 7: Overall preference from *wearer*'s perspective and eye contact ranking from *non-wearer*'s perspective

However, some participants (3/12) perceived the *text label* to be more comfortable for checking progress, as they could "quickly glance" at the progress without it significantly affecting social engagement. These three participants chose the *text label* as their first preference, indicating that it could also be suitable for certain users.

Except for the relaxation measure (i.e., *NB2*), there were no significant differences between progress *types* on conversation quality. The *circular bar* and *linear bar* were *more relaxing* to see than *text label* while conversing. Thus, statistically significant evidence is lacking to support *H3*, that the *circular bar* enables greater attention towards conversations. However, qualitative feedback supports the insight that *circular bar* minimizes attention switching between conversation partner and on-screen progress information. Multiple participants mentioned how the information shown on the *circular bar* is "immediately understandable", due to the shape and the graphical representation, meaning that they did not have spend too much time processing the information and could continue conversing with their partner. They also mentioned how it was very "obvious", and could thus focus more on the primary task than interpreting or anticipating the progress bar.

Overall, based on the study results, we recommend using *circular bar* to present progress/task completion notifications in face-to-face (1:1) conversations. But there are many other social interactions such as interviews, group meetings, and public speaking where progress notifications can be used, and we need further explorations to identify the most suited *type* in those scenarios and how they will be moderated by urgency and importance of such notifications.

6 GENERAL DISCUSSION

6.1 Study summary

In *study 1*, we found that when participants maintained uninterrupted eye contact in a simulated conversational setting, the *circular bar* enabled participants to receive progress notifications with less distraction, higher noticeability, comfortability, and accuracy. The *circular bar* is aligned with the ring-shaped paracentral and near-peripheral vision, which allowed users to interpret progress values at significantly higher accuracy than the *text label*. This was the preferred presentation type for the majority (83%) of participants. In *study 2*, we attempted to verify the results of *study 1* in a realistic conversation setting. We found that the *circular bar* was perceived as more effective in notifying participants of progress. They felt more relaxed with the *circular bar* than the *text label*, and the majority of users (58%) preferred it. While the general consensus is in favor of *circular bar*, there are merits to the other two designs.

As previously discussed, text is the most concise and direct presentation form but requires a certain amount of visual capability for viewing. The *linear bar* strikes a balance between noticeability and disruption but provides an uneven viewing experience: the areas of the bar closer to the region of central vision is more visible than areas of the bar that are further away. The *circular bar* and its circular shape make it easier to focus on the central location of the primary visual target, though its larger area can also be overwhelming. We analyzed the design trade-offs for deeper insights.

6.2 The role of text in secondary information display

While the paracentral and near-peripheral regions have certain capabilities to recognize text or symbols, it is still difficult for most participants to reliably read text using either paracentral or near-peripheral regions alone. Thus, displaying text entirely outside of the central vision is not recommended. However, our experiment also showed that participants could largely guess the meaning of the text information in the paracentral vision, indicating one can still explore this capability to offload some responsibilities from the central vision. One potential design is shown in Figure 8a. By placing the words across near-peripheral, paracentral, and central vision, the chance of understanding the meaning is significantly increased. While the text further away from the central vision is more difficult to read, readers can guess their meanings when considering them together with the text displayed in the central vision based on their contexts. We believe this strategy can be used to display familiar phrases while preserving the central vision for primary viewing tasks. In addition, there are fonts designed specifically for periphery viewing like 'Eido' [3] or 'PeriText' [21], which can be adopted if one wants to display text in the peripheral region of the eyes.

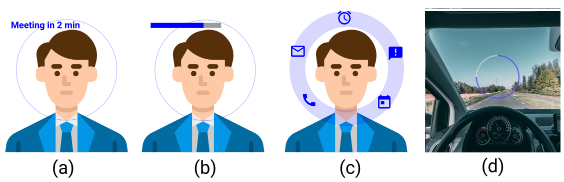


Figure 8: (a) Align important text to paracentral region, (b) Proposed *linear bar*, (c) Use of paracentral and near-peripheral vision for a glanceable radial menu or notification display, (d) Use of paracentral vision to show estimated arrival time. Image sources: Flaticon.com (photo3idea_studio), Unsplash.com and Google Material Icons

6.3 Trade-off between circular vs. linear visualization

We discovered that the circular shape has a unique advantage as it resembles the shape of our vision systems. By distributing information evenly around the central vision, it is also easier for the user to maintain focus. Thus, a circle is an ideal shape for designing attention-maintaining secondary visual displays. This paper explored one type of circular secondary information in progress updates, but this idea can be extended to other types of information; for example, Figure 8c shows a transparent radial menu displayed around the primary visual target. We believe such designs can help users to perceive the menu options while maintaining visual focus easily. Another example is a modified notification summarizer, the 'Scope' proposed by Dantzich et al. [41] whereby leaving the center blank and putting notifications around the ring, enables multiple glanceable categories of notifications (Figure 8c). A similar design could also be used in presenting trip status (e.g., estimated arrival time) to users as shown in Figure 8d.

The *linear bar*, although familiar, has a design that does not match well with our eyes' anatomy. Yet, the linear progress update visualization is more predictable as it always appears above the head (sec 5.7.3), thus easier for users to locate. Given that we know the importance of progress information is not evenly distributed (more discussion in the following section): the closer to the deadline, the more important the progress update becomes, so we could adjust the position of the *linear bar* so that the ending segment is closer to the central vision (Figure 8b), thus making it easier to perceive the information at the most important moments.

6.4 Timing of progress update

In the interview of *study 2*, we collected participants' feedback on the *intermittent persistence* of progress bars. The majority of participants (*wearers*) reported that they only checked the progress at the beginning and near the end of the conversation. Many of them (6/12) would like to have a progress bar appear *intermittent*ly with a lower frequency (e.g., 25%, 50%, 75%) at the beginning, and appear *intermittent*ly with a higher frequency (e.g., 80%, 90%, 100%) or even *continuous*ly near the end. These results imply that people have differently weighted needs on checking the progress on the notification bar. They are especially interested in being notified towards the end of the progress to prepare to take follow-up actions. Hence, we recommend a design of the *circular bar* with a hybrid *persistence* supporting user customization.

6.5 Social distance and perception of progress bars

In realistic conversations, the distance between the *wearer* and *non-wearer* can be shorter/longer than the distance we tested. When they get closer, the progress bars will move from the paracentral to near-peripheral to far-peripheral vision. In this situation, the *circular bar* and the *linear bar* can still be recognized due to their shape, but the *text label* would be harder to view unless they directly lookup (assuming all progress bars have fixed sizes). Similarly, if the distance between the *wearer* and *non-wearer* increases, the progress bars will move from paracentral to central vision where *wearer*s may be able to get precise information from the *text label* (if the font size is still visible), but the *circular bar* would still enable accurate estimation, while the *linear bar* would be harder to estimate due to shortening of perception length. While our study provides an initial set of promising results, further investigation is needed to understand how the size and position of the secondary information interplay with the social distance between conversation partners.

6.6 Attention-maintaining secondary information display design

As we mentioned in the introduction, we increasingly face multi-tasking scenarios where multiple sources of information need to be attended to in a very short period of time or almost simultaneously. In such cases, it's crucial to have design visualizations that can match the priority of the information source and the amount of attention it catches. Unimportant but attention-grabbing visualization is highly undesirable; visual design that carefully considers the priority with its attention demand will be more pleasing to look at. Our visual system has naturally evolved to have multiple regions that are responsible for different sources of information. They are equipped with different capabilities to naturally help us to prioritize the information we receive. While previous research has explored the usage of central vision, mid and far peripheral vision sub-systems, we believe the paracentral and near-peripheral vision is also worth exploring as they have different capabilities compared with other visual regions. This paper performed an initial investigation to demonstrate that these areas can be utilized to achieve better attention-maintaining secondary information displays, yet to realize its full potential requires further investigation. We hope this paper can raise awareness on this research topic, as we anticipate a possible paradigm shift towards heads-up and wearable computing. This line of research can help future designers develop better visualization techniques to mediate multiple information sources.

7 LIMITATIONS

In *study 1*, even though we used the gaze cursor and target regions, we could not control which vision region participants used to check the progress values. Since we could not record the vision region (i.e., para-central or near-peripheral) each individual used to check progress bars, we can not precisely say which region contributed more towards the current results. As this is an initial step towards understanding the use of paracentral and near-peripheral visualizations for OHMDs, we need further studies to precisely identify each region's advantage.

Even though we attempted to re-create a realistic scenario of casual conversations occurring between participant pairs in *study 2*, the context and setting remained artificial. Conversation topics were predetermined and provided, and participants were asked to sit at a fixed distance from each other. Although we provided training to minimize the effects of unfamiliarity, the lack of familiarity may still have interfered with participation. Moreover, as the studies continue, *non-wearer*s might have gotten more experienced with *study 2*, and it might have affected their ratings even though they were blind to conditions. Due to the COVID-19 restrictions, all participants wore masks during the studies, which might have impeded non-verbal forms of communication, with the exception of eye contact. From the feedback, we found that the majority of participants (75%) felt the conversations were natural once they started. We acknowledge the need for further studies to verify whether the same results hold when participants are engaged in 1:1 conversations in other realistic settings (e.g., outdoor walking).

Moreover, we only tested tech-savvy participants who were willing to try OHMDs. The results may not apply evenly to the rest of the population (e.g., older adults), as reception to emergent platforms such as the OHMD may differ, and visual perception styles vary too.

8 CONCLUSION AND FUTURE WORK

We utilized presenting secondary information in paracentral and near-peripheral vision using OHMDs and demonstrated that it could balance the secondary information reception and the quality of social interaction. We present the *circular bar*, an example design showing progress information on paracentral and near-peripheral vision during face-to-face conversation. Through the comparison of the *circular bar* with the *linear bar* and *text label* in two studies with both simulated and realistic conversational settings, we showed that the *circular bar* is preferred by most users and is effective in providing progress information without loss of eye contact. Future work could move forward by exploring more design solutions on utilizing paracentral and near-peripheral vision in other multitasking scenarios.

ACKNOWLEDGMENTS

This research was funded by AI.SG grant number AISG2-RP-2020-016. We thank all NUS-HCI lab members who helped to complete this project and volunteers who participated in our studies. We also thank reviewers for their valuable time and insightful comments that helped to improve this paper.

REFERENCES

[1] Michael Argyle and Mark Cook. 1976. Gaze and mutual gaze. (1976).

[2] Raquel Benbunan-Fich. 2012. The ethics and etiquette of multitasking in the workplace. *IEEE Technology and Society Magazine* 31, 3 (2012), 15–19. https://doi.org/10.1109/MTS.2012.2211391

[3] Jean-Baptiste Bernard, Carlos Aguilar, and Eric Castet. 2016. A New Font, Specifically Designed for Peripheral Vision, Improves Peripheral Letter and Word Recognition, but Not Eye-Mediated Reading Performance. *PloS One* 11, 4 (2016), 25. https://doi.org/10.1371/journal.pone.0152506

[4] Isha Chaturvedi, Farshid Hassani Bijarbooneh, Tristan Braud, and Pan Hui. 2019. Peripheral vision: a new killer app for smart glasses. In *Proceedings of the 24th International Conference on Intelligent User Interfaces - IUI '19*. ACM Press, Marina del Ray, California, 625–636. https://doi.org/10.1145/3301275.3302263

[5] Soon Hau Chua, Simon T. Perrault, Denys J. C. Matthies, and Shengdong Zhao. 2016. Positioning Glass: Investigating Display Positions of Monocular Optical See-Through Head-Mounted Display. In *Proceedings of the Fourth International Symposium on Chinese CHI - ChineseCHI2016*. ACM Press, San Jose, USA, 1–6. https://doi.org/10.1145/2948708.2948713

[6] Marina Cidota, Stephan Lukosch, Dragos Datcu, and Heide Lukosch. 2016. Workspace Awareness in Collaborative AR using HMDs: A User Study Comparing Audio and Visual Notifications. In *Proceedings of the 7th Augmented Human International Conference 2016 on - AH '16*. ACM Press, Geneva, Switzerland, 1–8. https://doi.org/10.1145/2875194.2875204

[7] Enrico Costanza, Samuel A. Inverso, Elan Pavlov, Rebecca Allen, and Pattie Maes. 2006. eye-q: eyeglass peripheral display for subtle intimate notifications. In *Proceedings of the 8th conference on Human-computer interaction with mobile devices and services - MobileHCI '06*. ACM Press, Helsinki, Finland, 211. https://doi.org/10.1145/1152215.1152261

[8] Saverio Debernardis, Michele Fiorentino, Michele Gattullo, Giuseppe Monno, and Antonio Emmanuele Uva. 2014. Text Readability in Head-Worn Displays: Color and Style Optimization in Video versus Optical See-Through Devices. *IEEE Transactions on Visualization and Computer Graphics* 20, 1 (Jan. 2014), 125–139. https://doi.org/10.1109/TVCG.2013.86

[9] docstocTV. 2014. What Kind of Business Is Crowdfunding Best For? https://www.youtube.com/watch?v=kiwvTdqRBXk

[10] Cambridge ESOL. 2008. *Speaking Test Preparation Pack for FCE Paperback with DVD*. Cambridge University Press.

[11] Uwe Gruenefeld, Tim Claudius Stratmann, Jinki Jung, Hyeopwoo Lee, Jeehye Choi, Abhilasha Nanda, and Wilko Heuten. 2018. Guiding Smombies: Augmenting Peripheral Vision with Low-Cost Glasses to Shift the Attention of Smartphone Users. In *2018 IEEE International Symposium on Mixed and Augmented Reality Adjunct (ISMAR-Adjunct)*. IEEE, Munich, Germany, 127–131. https://doi.org/10.1109/ISMAR-Adjunct.2018.00050

[12] Carl Gutwin, Andy Cockburn, and Ashley Coveney. 2017. Peripheral Popout: The Influence of Visual Angle and Stimulus Intensity on Popout Effects. In *Proceedings of the 2017 CHI Conference on Human Factors in Computing Systems*. ACM, Denver Colorado USA, 208–219. https://doi.org/10.1145/3025453.3025984

[13] Edward Twitchell Hall. 1966. *The hidden dimension*. Vol. 609. Garden City, NY: Doubleday.

[14] Sandra G. Hart. 2006. Nasa-Task Load Index (NASA-TLX); 20 Years Later. *Proceedings of the Human Factors and Ergonomics Society Annual Meeting* 50, 9 (2006), 904–908. https://doi.org/10.1177/154193120605000909

[15] Roy S. Hessels. 2020. How does gaze to faces support face-to-face interaction? A review and perspective. *Psychonomic Bulletin & Review* 27, 5 (Oct. 2020), 856–881. https://doi.org/10.3758/s13423-020-01715-w

[16] Sebastian Hobert and Matthias Schumann. 2016. Application Scenarios of Smart Glasses in the Industrial Sector: Results of an Empirical Study Among Domain Experts. *i-com* 15, 2 (Aug. 2016), 133–143. https://doi.org/10.1515/icom-2016-0016

[17] Yoshio Ishiguro and Jun Rekimoto. 2011. Peripheral vision annotation: noninterference information presentation method for mobile augmented reality. In *Proceedings of the 2nd Augmented Human International Conference on - AH '11*. ACM Press, Tokyo, Japan, 1–5. https://doi.org/10.1145/1959826.1959834

[18] Kai Klinker, Lisa Berkemeier, Benedikt Zobel, H. Wüller, Veronika Huck-Fries, Manuel Wiesche, H. Remmers, Oliver Thomas, and H. Krcmar. 2018. Structure for innovations: A use case taxonomy for smart glasses in service processes.

[19] Elisa Maria Klose, Nils Adrian Mack, Jens Hegenberg, and Ludger Schmidt. 2019. Text Presentation for Augmented Reality Applications in Dual-Task Situations. In *2019 IEEE Conference on Virtual Reality and 3D User Interfaces (VR)*. IEEE, Osaka, Japan, 636–644. https://doi.org/10.1109/VR.2019.8797992

[20] Marion Koelle, Matthias Kranz, and Andreas Möller. 2015. Don't look at me that way!: Understanding User Attitudes Towards Data Glasses Usage. In *Proceedings of the 17th International Conference on Human-Computer Interaction with Mobile*

Devices and Services. ACM, Copenhagen Denmark, 362–372. https://doi.org/10.1145/2785830.2785842
[21] Pin-Sung Ku, Yu-Chih Lin, Yi-Hao Peng, and Mike Y. Chen. 2019. PeriText: Utilizing Peripheral Vision for Reading Text on Augmented Reality Smart Glasses. In *2019 IEEE Conference on Virtual Reality and 3D User Interfaces (VR)*. 630–635. https://doi.org/10.1109/VR.2019.8798065
[22] Gordon E Legge, J. Stephen Mansfield, and Susana T. L Chung. 2001. Psychophysics of reading: XX. Linking letter recognition to reading speed in central and peripheral vision. *Vision Research* 41, 6 (March 2001), 725–743. https://doi.org/10.1016/S0042-6989(00)00295-9
[23] Andr\'{e}s Lucero and Akos Vetek. 2014. NotifEye: using interactive glasses to deal with notifications while walking in public. In *Proceedings of the 11th Conference on Advances in Computer Entertainment Technology - ACE '14*. ACM Press, Funchal, Portugal, 1–10. https://doi.org/10.1145/2663806.2663824
[24] Kris Luyten, Donald Degraen, Gustavo Rovelo Ruiz, Sven Coppers, and Davy Vanacken. 2016. 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*. ACM Press, Santa Clara, California, USA, 487–497. https://doi.org/10.1145/2858036.2858339
[25] Sven Mayer, Lars Lischke, Paweł W. Woźniak, and Niels Henze. 2018. Evaluating the Disruptiveness of Mobile Interactions: A Mixed-Method Approach. In *Proceedings of the 2018 CHI Conference on Human Factors in Computing Systems - CHI '18*. ACM Press, Montreal QC, Canada, 1–14. https://doi.org/10.1145/3173574.3173980
[26] Gerard McAtamney and Caroline Parker. 2006. An examination of the effects of a wearable display on informal face-to-face communication. In *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems (CHI '06)*. Association for Computing Machinery, New York, NY, USA, 45–54. https://doi.org/10.1145/1124772.1124780
[27] Michel Millodot. 2008. *Dictionary of Optometry and Visual Science* (7th edition ed.). Butterworth-Heinemann, Edinburgh ; New York.
[28] Takuro Nakuo and Kai Kunze. 2016. Smart glasses with a peripheral vision display. In *Proceedings of the 2016 ACM International Joint Conference on Pervasive and Ubiquitous Computing: Adjunct*. ACM, Heidelberg Germany, 341–344. https://doi.org/10.1145/2968219.2971393
[29] Tien T. Nguyen, Duyen T. Nguyen, Shamsi T. Iqbal, and Eyal Ofek. 2015. The Known Stranger: Supporting Conversations between Strangers with Personalized Topic Suggestions. In *Proceedings of the 33rd Annual ACM Conference on Human Factors in Computing Systems*. ACM, Seoul Republic of Korea, 555–564. https://doi.org/10.1145/2702123.2702411
[30] Eyal Ofek, Shamsi T. Iqbal, and Karin Strauss. 2013. Reducing disruption from subtle information delivery during a conversation: mode and bandwidth investigation. In *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems (CHI '13)*. Association for Computing Machinery, New York, NY, USA, 3111–3120. https://doi.org/10.1145/2470654.2466425
[31] Julius Panero and Martin Zelnik. 1979. *Human dimension & interior space: a source book of design reference standards*. Watson-Guptill.
[32] Benjamin Poppinga, Niels Henze, Jutta Fortmann, and Wilko Heuten. 2012. AmbiGlasses – Information in the Periphery of the Visual Field. In *Mensch & Computer 2012: interaktiv informiert – allgegenwärtig und allumfassend!?* 153–162.
[33] K. Rayner. 1998. Eye movements in reading and information processing: 20 years of research. *Psychological Bulletin* 124, 3 (Nov. 1998), 372–422. https://doi.org/10.1037/0033-2909.124.3.372
[34] Bradley James Rhodes. 2000. *Just-In-Time Information Retrieval*. Ph. D. Dissertation.
[35] Ruth Rosenholtz. 2016. Capabilities and Limitations of Peripheral Vision. *Annual Review of Vision Science* 2, 1 (Oct. 2016), 437–457. https://doi.org/10.1146/annurev-vision-082114-035733
[36] Rufat Rzayev, Susanne Korbely, Milena Maul, Alina Schark, Valentin Schwind, and Niels Henze. 2020. Effects of Position and Alignment of Notifications on AR Glasses during Social Interaction. In *Proceedings of the 11th Nordic Conference on Human-Computer Interaction: Shaping Experiences, Shaping Society*. ACM, Tallinn Estonia, 1–11. https://doi.org/10.1145/3419249.3420095
[37] Dario D Salvucci. 2013. Multitasking. (2013).
[38] Elizabeth R. Schotter, Bernhard Angele, and Keith Rayner. 2012. Parafoveal processing in reading. *Attention, Perception, & Psychophysics* 74, 1 (Jan. 2012), 5–35. https://doi.org/10.3758/s13414-011-0219-2
[39] H. Strasburger, I. Rentschler, and M. Juttner. 2011. Peripheral vision and pattern recognition: A review. *Journal of Vision* 11, 5 (Dec. 2011), 13–13. https://doi.org/10.1167/11.5.13
[40] M. Iftekhar Tanveer, Emy Lin, and Mohammed (Ehsan) Hoque. 2015. Rhema: A Real-Time In-Situ Intelligent Interface to Help People with Public Speaking. In *Proceedings of the 20th International Conference on Intelligent User Interfaces - IUI '15*. ACM Press, Atlanta, Georgia, USA, 286–295. https://doi.org/10.1145/2678025.2701386
[41] Maarten van Dantzich, Daniel Robbins, Eric Horvitz, and Mary Czerwinski. 2002. Scope: providing awareness of multiple notifications at a glance. In *Proceedings of the Working Conference on Advanced Visual Interfaces - AVI '02*. ACM Press, Trento, Italy, 267. https://doi.org/10.1145/1556262.1556306
[42] Zheng Wang and John M Tchernev. 2012. The "myth" of media multitasking: Reciprocal dynamics of media multitasking, personal needs, and gratifications. *Journal of Communication* 62, 3 (2012), 493–513.
[43] Christopher D. Wickens, Justin G. Hollands, Simon Banbury, and Raja Parasuraman. 2015. *Engineering psychology and human performance* (4th ed.). Pearson Education.
[44] Kristin Williams, Karyn Moffatt, Denise McCall, and Leah Findlater. 2015. Designing Conversation Cues on a Head-Worn Display to Support Persons with Aphasia. In *Proceedings of the 33rd Annual ACM Conference on Human Factors in Computing Systems*. ACM, Seoul Republic of Korea, 231–240. https://doi.org/10.1145/2702123.2702484
[45] Zyxwv99. 2021. Field of view. https://commons.wikimedia.org/wiki/File:Field_of_view.svg Retrieved Sept 8, 2021 from https://commons.wikimedia.org/wiki/File:Field_of_view.svg.

A *STUDY 1*

A.1 Measures in *study 1*

Table 2 indicates participants' mean performance related to progress recognition while Table 3 indicates the mean performance related to quality of conversation.

A.2 Individual NASA-TLX Indices

Overall, *circular bar* and *linear bar* had significantly lower ($p < 0.01$) task load than *text label*. A repeated-measures ANOVA showed significant main effects of *type* on the overall score ($F_{2,22} = 16.646$, $p < 0.001$) as well as all individual indices ($p < 0.01$). A post-hoc analysis with Bonferroni correction revealed that for all measures *circular bar* and *linear bar* yielded significantly lower ($p < 0.05$) task load results than *text label*. But there was no significant differences between *circular bar* and *linear bar*, even though *circular bar* had the lowest average task loads for all measures. On all indices including overall score (Figure 9), the sorted order of task-load from lower to higher was; *circular bar* < *linear bar* < *text label*.

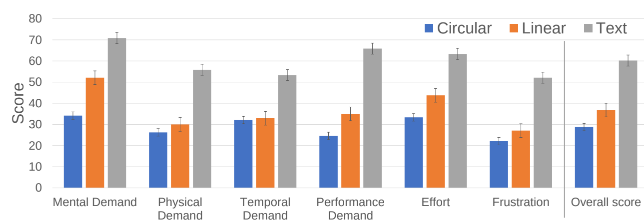


Figure 9: NASA-TLX scores for *circular bar*, *linear bar*, and *text label*. Error bars represent standard errors.

B *STUDY 2*

B.1 Measures in *study 2*

Table 4 indicates *wearers*' perceived mean ratings on progress *types* while Table 5 indicates both *wearers*' and *non-wearers*' perceived mean ratings on conversation.

C PROGRAMMING CODES

You can find the codes at https://github.com/NUS-HCILab/CircularProgressBar. If you have any issues accessing the code, please contact authors.

Table 2: Progress perception measures in simulated conversation setting (N = 12). Colored bars show the relative value of each measure for different progress *types*. ⋆ and † represent significant ($p < 0.05$) post-hoc tests.

Measure	*Progress Accuracy %*		*Noticeability*		*Ease of Identification*		*Comfortability*	
Format	M	SD	M	SD	M	SD	M	SD
Circular bar	96.32⋆†	2.15	6.67⋆†	0.65	6.25⋆	1.14	5.50⋆	1.68
Linear bar	93.89⋆	3.82	5.67†	0.99	5.08†	1.17	4.83†	1.19
Text label	91.47†	8.71	4.25⋆	1.66	2.17⋆†	1.12	2.25⋆†	0.75

Table 3: Quality of conversation in simulated conversation setting (N = 12). Colored bars show the relative value of each measure for different progress *types*. ⋆ and † represent significant ($p < 0.05$) post-hoc tests.

Measure	*Degree of Distraction %*		*Perceived Interruption*		*RTLX*	
Format	M	SD	M	SD	M	SD
Circular bar	2.88	4.74	31.92⋆	23.42	28.75⋆	18.82
Linear bar	2.81	7.47	39.75†	22.32	36.81†	12.58
Text label	5.35	10.75	74.92⋆†	13.55	60.21⋆†	16.54

Table 4: Perceived rating on progress *types* (N = 12). Colored bars show the relative value of each measure for different progress *types*. ⋆ represents significant ($p < 0.05$) post-hoc tests. † and ‡ represents non-significant ($p > 0.05$) yet $p < 0.10$ post-hoc tests.

Measure	*Noticeability*		*Comfortability*		*Perceived Effectiveness*	
Format	M	SD	M	SD	M	SD
Circular bar	6.33⋆	0.99	5.25†	1.14	6.17⋆	0.84
Linear bar	4.92⋆	1.17	4.42†‡	1.44	5.00⋆	1.54
Text label	5.25	1.66	5.33‡	1.30	5.42	1.56

Table 5: Perceived rating in conversation setting (N = 12) by *wearer* [W] and *non-wearer* [N]. Colored bars show the relative value of each measure for different progress *types*. † and ‡ represent non-significant ($p > 0.05$) yet $p < 0.10$ post-hoc tests.

Measure	AC1		AC2		EC1		EC2		NB1		NB2	
Format	M	SD	M	SD	M	SD	M	SD	M	SD	M	SD
[W] *Circular bar*	6.00	1.28	5.50	1.31	5.83	0.94	-	-	5.17	1.27	5.50†	0.91
[W] *Linear bar*	6.08	1.00	5.83	1.19	5.92	1.17	-	-	5.58	1.24	5.67‡	0.78
[W] *Text label*	6.17	1.03	5.75	0.87	5.92	1.17	-	-	5.25	1.22	4.67†‡	1.56
[N] *Circular bar*	6.67	0.49	6.50	0.65	6.33	0.78	6.25	0.75	6.08	0.67	6.50	0.67
[N] *Linear bar*	6.50	0.67	6.67	0.49	6.67	0.49	6.25	0.62	6.25	0.62	6.42	0.90
[N] *Text label*	6.50	0.91	6.67	0.49	6.42	0.67	6.17	0.39	6.33	0.65	6.67	0.65