Effects of Position and Alignment of Notifications on AR Glasses during Social Interaction

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ABSTRACT

Notifications are one of the smartphones' key features. However, notifications can be disruptive, especially during social interaction. Augmented reality (AR) glasses can embed notifications directly into the user's field of view and enable reading them while being engaged in a primary task. However, for efficient notification presentation using AR glasses, it is necessary to understand how notifications should be displayed without negatively affecting social interaction. Therefore, we conducted a study with 32 participants (16 pairs) using AR glasses to investigate how to display notifications during face-to-face communication. We compared center and top-right positions for notifications while aligning them relative to the user's field of view or with the conversation partner. We found significant effects of notification position and alignment on how notifications are perceived using AR glasses during face-to-face communication. Insights from our study inform the design of applications for AR glasses that support displaying digital notifications.

CCS CONCEPTS

• **Human-centered computing** → **User studies**; **Mixed / augmented reality**.

KEYWORDS

Notification, AR, Face-to-face communication, Interruption.

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1 INTRODUCTION

Permanent mobile connectivity has augmented social interaction among smartphone users. Previous work showed that smartphones could satisfy the users' desire to remain permanently connected to other people [51]. Most smartphone applications, especially communication applications, attract users' attention through push notifications. A notification is a visual, auditory, or haptic alert that draws users' attention to proactively delivered information [21, 41]. Today, smartphone users receive a large number of notifications throughout the day [39]. As smartphones are usually kept in a reachable distance [37], ill-timed notifications can lead to distraction during social interaction [32, 33, 36, 39]. As a result of a received notification, the user's attention shifts from the surrounding setting to the device. Consequently, this can lead to disconnection from co-located social interaction [43] and *phubbing* – preferring paying attention to the smartphone rather than the other person in the social setting [6]. On the one hand, notifications keep smartphone users informed about their social relations. On the other hand, they can distract people during physically co-located social interaction. To prevent users from completely disabling notifications and potentially developing a sense of disconnectivity [40], design solutions are required to solve this issue. This is particularly worth considering, as the use of technology in public spaces does not necessarily detract from conversing with strangers [5]. This suggests that using appropriately designed technology during face-to-face communication may blend in with such social interactions [34].

Compared to smartphones, smart glasses can augment human vision by allowing viewing information continuously through see-through displays while simultaneously engaging with other activities. Such devices make it possible to access information without the need to hold them in hand. By placing information directly in the user's field of view, smart glasses allow viewing information without abrupt attention shifts between the device and the surrounding environment. In addition to the functionality of smart glasses, augmented reality (AR) glasses allow embedding information into the scene. Consequently, AR glasses enable users to seamlessly view the information by displaying it on or around the users' area of interest. For example, a notification can be displayed on or around the interlocutor's face during social interaction, since it was shown that the interlocutor's eyes and mouth are dominant target zones during social interaction [44]. Furthermore, AR glasses allow utilizing any area in front of the user. Thus, notifications, for example, can be directly presented in front of the user or aligned with the user's area of interest, which is the interlocutor in the social interaction context. Therefore, displaying notifications using AR glasses might be promising to reduce distractions during social interaction. It could make users aware of a received notification without requiring to pick up and look at another device. However, it is unclear how notifications should be presented using AR glasses and how viewing the notification in a social setting affects social interaction.

In this paper, we investigate the effects of position and alignment of notifications on binocular see-through AR glasses during social interaction. Through a study, we compared center and top-right positions while aligning notifications either relative to the user's field of view or with the conversation partner. We conducted the study with an application we developed for Microsoft's HoloLens. To create a social setting, pairs of participants discussed various topics during face-to-face communication while one of them was receiving notifications on the AR glasses. By comparing the position and alignment of notifications on AR glasses during face-to-face communication, we make the following contributions: (1) We show that aligning notifications with the conversation partner reduces users' task load and perceived intrusiveness of notifications. (2) We demonstrate that notifications displayed in the center are perceived as the most urgent when aligned relative to the user's field of view. However, notifications in the top-right position are perceived as the most urgent when aligned with the communication partner.

2 RELATED WORK

Our work is based on previous research investigating interruption caused by notifications, smart glasses usage during social interaction, displaying notifications, and text placement on smart glasses that we discuss in the following.

2.1 Digital Notifications

Smartphones generate visual, auditory, and haptic alerts to attract users' attention to communicate important messages, upcoming calendar events, and calls. Previous work showed that smartphone owners receive a large number of notifications, and they are viewed within a very short time [9, 39, 48]. To avoid disappointing others and conform with their expectations, a notification recipient feels social pressure to attend notifications even in an inappropriate moment, such as during social interaction [22]. Therefore, ill-timed notifications can cause interruption during a primary task. Stothart *et al.* [49] showed that notifications significantly reduce the performance of an attention-demanding task, even when users do not directly interact with a mobile device during the task. Mehrotra *et al.* [32] showed that the disruptiveness of a notification depends on its presentation, alert type, sender-recipient relationship, as well as the type, completion level, and complexity of the task in which the user is engaged. Kushlev *et al.* [28] found that smartphone notifications increase the level of inattention, which predicts lower productivity and psychological well-being.

Previous work showed that although smartphone owners apply various management strategies to limit their smartphone use, they often fail due to a lack of self-regulation [26]. Therefore, a body of work focused on supporting users in limiting their smartphone use [13, 25, 26]. Moreover, previous work also investigated strategies for triggering notifications based on opportune moments [10, 38]. However, disabling notifications can make users feel anxious and lonely [40]. Furthermore, users might feel social pressure through heightened expectations of viewing and answering to a notification [19].

Previous work also investigated displaying notifications on smart glasses. In comparison to smartphones, smart glasses require fewer attention shifts. Orlosky *et al.* [35] showed that users are more aware of the surrounding environment while using smart glasses compared to the use of smartphones. They presented a dynamic text management system that changes the position of a text message on a see-through smart glasses as the user moves to increase readability. Their results revealed that users prefer text messages placed in the background compared to placing them on the smart glasses' screen. Lucero and Vetek [29] conducted a study in which participants walked on a busy street while receiving social network notifications on smart glasses. They found that a minimalistic user interface to display notifications supported participants in keeping track of their surroundings when they dealt with incoming notifications. A body of work also investigated displaying notifications on immersive head-mounted display-based virtual reality [14, 46].

2.2 Smart Glasses Use during Social Interaction

Previous work investigated the use of smart glasses during social interaction. McAtamney and Parker [31] investigated how smart glasses affect face-to-face conversation by comparing three conditions: no smart glasses, smart glasses with an active display, and smart glasses with an inactive display. They found that wearing smart glasses without an active display does not affect a face-to-face conversation. However, smart glasses with an active display can negatively affect the quality of conversations and reduce the eye-contact. Similarly, Häkkilä *et al.* [15] highlighted that effects on face-to-face interaction with other people can negatively affect the social acceptability of smart glasses. Ofek *et al.* [34] compared visual and auditory information presentations during the face-to-face conversation. They observed that participants could process information while talking with the other participants without this being detected by an interlocutor. Furthermore, they found that participants performed better if the information was delivered while they were not speaking. Alallah *et al.* [2] found that less noticeable input modalities on smart glasses are more socially acceptable. Akkil *et al.* [1] indicated that applications for smart glasses supposed to be used during social interaction should minimize the use of eyes for interaction and free them for face-to-face conversation.

2.3 Text Presentation on Smart Glasses

Notifications are mainly based on textual information. Previous work investigated various aspects of text styles and placements on see-through head-worn glasses. Gabbard *et al.* [12] compared text drawing styles for see-through AR glasses using outdoor background textures and natural lighting. Their results suggest using green text or a billboard style (*i.e.*, colored text on a semi-transparent plane with a different color) on AR glasses. In a study, Jankowski *et al.* [23] compared different text drawing styles, image polarity, and background style on readability. Results showed that the billboard drawing styles results in the fastest and highest performance. Furthermore, white text with a black billboard outperforms black text with a white billboard. Debernardis *et al.* [8] suggested that for indoor augmented reality applications, a good combination of text drawing style is a white text with a blue billboard. Furthermore, to convey color information in a text message, the color should be used for the billboard, and the text should be white.

Tanaka *et al.* [50] investigated text placement while on the move. They proposed a method that analyzes the background image taken from a camera attached to smart glasses to find an optimal area for placing text. Chua *et al.* [7] compared nine display positions of monocular smart glasses in a dual-task scenario. Participants drove in a car simulator and reacted to three types of notifications (color, application icon with a number and a text) displayed in different positions. The results showed that color notifications increase reaction time and decrease the error rate. The authors provided design recommendations for the positions of monocular smart glasses' displays in dual-task scenarios: 1) Middle-right, top-center, and top-right are suitable for dual-task scenarios when smart glasses have to be used for a long time, center of vision is important for the primary task or the secondary stimuli is less urgent. 2) When a high noticeability of the secondary task is required, middle-center or bottom-center positions should be used for dual-task scenarios. Rzayev *et al.* [47] compared top-right, center and bottom-center text positions. Participants were reading text presented with rapid serial visual presentation (RSVP) or line-by-line while walking and sitting. They found that text displayed in the top-right increases the perceived workload and reduces comprehension. Furthermore, RSVP results in higher comprehension while sitting, and line-by-line reading yields better comprehension while walking. In a study, Rzayev *et al.* [45] compared three positions for translation text in a vocabulary learning task using AR smart glasses. They found that displaying translations on top of foreign words significantly reduces comprehension and increases perceived workload.

2.4 Summary

In summary, mobile notifications are essential to be informed about important messages and calendar events. However, previous research showed that notifications during social interaction might negatively affect the primary activity. However, AR glasses enable seamlessly embedding information into the scene in front of the user, which does not require the user to switch attention from the main activity completely. Thus, using AR glasses to display notifications during social interaction is a promising approach to read important notifications and keep up the interaction. Previous work investigated displaying textual content using AR smart glasses while aligning the content with the background or the glasses and comparing different placements without considering social interaction scenarios. Therefore, insights on the position and alignment of notifications in AR glasses during social interaction are missing.

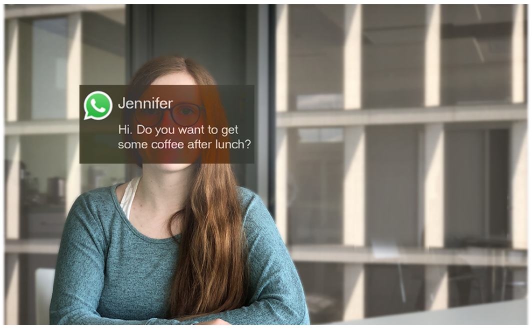
3 METHOD

We conducted a study to investigate how receiving notifications on AR glasses affects social interaction. Similar to previous work [30, 34], we used a face-to-face conversation as a typical type of social interaction scenario. Pairs of participants held a face-to-face conversation with one of them receiving notifications on AR glasses. As only one participant received notifications, we refer to participants who received notifications as the *receiver* and participants who did not receive notifications as the *observer*. During the study, only *receiver*s were wearing AR glasses. In the study, we compared two notification POSITIONS and two ALIGNMENTS. The two POSITIONS are *center*, as this is the most noticeable position suggested by Chua *et al.* [7], and *top-right*, as this is the display position of Google Glass.

Notifications were displayed either in the *receiver*'s direct field of view (*receiver-locked*) or aligned with the *observer*'s face (*observer-locked*). In the *receiver-locked* conditions, notifications were displayed one meter in front of the receiver. They were aligned to the *receiver*'s field of view and thereby in a fixed position of the AR glasses. In the *observer-locked* conditions, notifications were aligned with the *observer*'s face and displayed in the same distance from the *receiver* as the *observer*'s face. In the *observer-locked* ALIGNMENT with *center* POSITION, notifications were displayed in front of the *observer*'s face as people usually look at the eyes and mouth of the interlocutor during social interaction [44]. Notifications were presented in the top-right of the interlocutor's face in the *observer-locked* ALIGNMENT with *top-right* POSITION. For the *observer-locked* conditions, we did not use positions further away as they might be inappropriate (*e.g.*, chest area of a participant) or minimize the eye contact with the conversation partner [1].

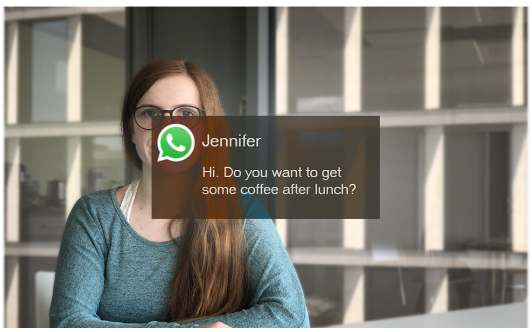
3.1 Study Design

We conducted the study using POSITION and ALIGNMENT as within-subjects variables, resulting in four conditions (see Figure 1). The order of POSITION and ALIGNMENT was counterbalanced across all participants. At the end of each condition, we handed different questionnaires to the *receiver* and the *observer*. The *receiver*s evaluated the usability using the System Usability Scale (*SUS*) [4] and rated the perceived task load using the Raw TLX (*RTLX*) [18] questionnaire. Furthermore, *receiver*s rated if the *presentation* and *duration* of notifications were appropriate, if it was easy to concentrate on the notifications during the conversation (*concentrateOnNotification*), and if they could concentrate on the conversation (*concentrateOnConversation*). All questions were mandatory Likert items and had to be answered on a seven-point scale ranging from *strongly disagree* to *strongly agree*. Moreover, we asked participants to answer four 7-point Likert scale questions that were adapted from Ghosh *et al.* [14]: (1) How easy or difficult was it to notice the notification? (*noticeability*); (2) Once you notice the notification, how easy or difficult was it to understand what it stands for? (*understandability*); (3) What level of urgency does the notification convey? (perceived *urgency*) and (4) How much of a hindrance was the notification to the overall communication experience (perceived *intrusiveness*).



(a) *Observer-locked* ALIGNMENT with *center* POSITION

(b) *Observer-locked* ALIGNMENT with *top-right* POSITION



(c) *Receiver-locked* ALIGNMENT with *center* POSITION

(d) *Receiver-locked* ALIGNMENT with *top-right* POSITION

Figure 1: The four conditions used in the study.

At the end of each condition, to determine the social acceptability of using AR glasses during a face-to-face conversation, we asked *observer*s to rate six Likert items that were adapted from Profita *et al.* [42]. The Likert items had the following statements: (1) It looked awkward that my conversation partner was wearing the AR glasses (*Awkward*); (2) It looked normal that my conversation partner was wearing the AR glasses (*Normal*); (3) It was appropriate for my communication partner to wear the AR glasses in this setting (*Appropriate*); (4) It was rude for my communication partner to wear the AR glasses (*Rude*); (5) I felt uncomfortable watching my communication partner wearing the AR glasses (*Uncomfortable*) and (6) I felt to be distracted by my communication partner wearing AR glasses (*Distracting*). Furthermore, we asked *observers* with two questions to evaluate if they (*observerConcentrated*) and their conversation partner (*receiverConcentrated*) could concentrate on the conversation. All questions were mandatory and had to be answered on a seven-point scale ranging from *strongly disagree* to *strongly agree*. Finally, we conducted semi-structured interviews with *receiver* and *observer* separately.

3.2 Apparatus

To conduct the study, we developed an application for Microsoft HoloLens that enables displaying notifications in two positions and either aligned relative to the field of view or with the communication partner's face. We used Unity 2018.3.12f1 to develop the application. We used realistic notifications for the study. However, to protect participants' privacy, one of the authors used the Notification Log app [52] to collect his notifications. We selected 20 notifications from six different apps and categorized them into messaging, group messaging, email, social, and non-social, approximating the average distribution of notifications received per day [41]. As a sender name in notifications, we used first names that were common in the country of the study. Notifications had a rectangular shape, were displaying sender name, notification text and the app icon. We displayed the notifications using white sans-serif text with a semi-transparent dark billboard, as suggested by previous work [8, 23] (see Figure 1).

During the study, the distance between the *receiver* and *observer* was approximately 2 meters. The *receiver-locked* ALIGNMENT displayed the notifications in one-meter distance from the *receiver* to avoid the discomfort due to vergence accommodation conflict, as recommended by the HoloLens design guidelines [1]. For the *observer-locked* ALIGNMENT, we used HoloFace [27], an open-source framework for face alignment. Based on pilot tests, we decided for the font sizes of 20 pt for the *receiver-locked* conditions and 30 pt for the *observer-locked* conditions. In the *center* POSITION, the application displayed notifications either at the center of the *receiver*'s field of view or of the face of the communication partner based on the ALIGNMENT. For the *top-right* POSITION, notifications were presented either top-right of the *receiver*'s field of view or of the *observer*'s face (see Figure 1).

[1]https://docs.microsoft.com/en-us/windows/mixed-reality/comfort

Figure 2: The participant wearing a HoloLens (*receiver*) is receiving notifications while talking with the other participant (*observer*).

3.3 Task

During the study, participants had one face-to-face conversation session per condition (see Figure 2). At the beginning of each conversation session, a researcher provided a topic by asking a question. Similar to Mayer *et al.* [30], we used the following four questions from the CAE speaking test by [11]: (1) "Some people say that computers are helping to create a generation without social skills. What is your opinion?" (2) "What are the advantages and disadvantages of shopping by a computer?" (3) "How far do you agree that the computer is the greatest invention of modern times?" (4) "A lot of personal information about all of us is now kept on computers. Do you find this worrying?" As backup questions, considering that most of the potential participants were students, we prepared student-related topics, such as distance learning, semester abroad and mandatory participation in the lectures. Each session took seven minutes. A researcher motivated both the observer and receiver to actively engage in the discussion. In case the discussion was less active, a researcher asked additional questions or switched to the next topic. All pairs of participants received the same topics to discuss. During each conversation session, one of the participants (*receiver*) received notifications on the AR glasses. During the first two minutes of a session, no notification was displayed to warm up the conversation. During the following five minutes of a session, five notifications were randomly displayed. We made sure that notifications were always at least 20 seconds apart. Notifications disappeared after 15 seconds.

3.4 Procedure

We assigned participants to two groups, *receiver* and *observer*. Similarly to Mayer *et al.* [30], we invited participants to the study with the title *Stress in Conversation* to ensure that participants do not know about the notifications provided on the AR glasses. The study was guided by two researchers. As the pair of participants arrived, they were separated into two different rooms. We explained the general aim and procedure of the study. We told the participants assigned to be the *observer* that there will be four sessions of face-to-face conversation and that the other participant will wear a HoloLens. We, however, indicated that the HoloLens should not be part of the conversations. Afterward, the participant filled a demographic questionnaire and signed a consent form.

The participants assigned to be the *receiver* were handed a HoloLens, we helped them wear it and explained how it works. The *receiver* was told that notifications will be displayed on the AR glasses while having a face-to-face conversation. We further explained that notifications will be displayed for 15 seconds and that it is important to pay attention to the conversation and to read the notifications. We also explained that the other participant is unaware of the notifications and that they should not be discussed during the study. To ensure that *receiver* would actually read the notifications, we informed them that at the end of each session, we will ask them if they can remember the notifications. Then the participant had a training session to try the notifications in all four conditions. As the *receiver* was ready, a researcher started the first condition on the HoloLens.

Afterward, the *observer* was guided to the same room, and both participants were seated on opposite sides of a table (see Figure 2). The distance between participants was approximately 2 meters that are within the social distance range (1.2 m - 3.6 m) defined by Hall [16]. As both participants were familiar with the study, we provided the first topic to discuss. For the HoloLens app, the start of the 7-minute discussion was initialized with the clicker that a researcher pressed. After 7 minutes, we stopped the discussion, helped the *receiver* to take off the HoloLens and provided both participants with a laptop to fill in the abovementioned questionnaires (see section 3.1). Furthermore, the *receiver* marked the received notifications in the list of ten similar notifications. This step was needed to ensure that the *receiver* actually read the notifications. While participants were filling the questionnaires, a researcher switched to the next condition on the HoloLens. Afterward, participants continued with the next POSITION × ALIGNMENT conditions. These steps were repeated until the participants were subject to all four conditions. In the end, we conducted semi-structured interviews with both participant pairs separately. The study took about an hour per participant pair.

3.5 Participants

We recruited 32 participants (16 females, 16 males) through our university's mailing list. Their average age was M = 23.1 (SD = 3.42) years, and most were university students with a technical background. Eight participants wore glasses. We ensured that all participants assigned to be *receiver* had normal vision. While 17 participants never used an AR application, 10 used it more than once, and 5 used an AR application more than three times. 28 participants had never interacted with a HoloLens. Participants received course credits for participating in the study.

4 RESULTS

During the study, 32 participants (16 pairs) completed four conversation rounds for each of the POSITION × ALIGNMENT pairs and received five notifications during each conversation round. For the evaluation, we performed a quantitative analysis of the collected

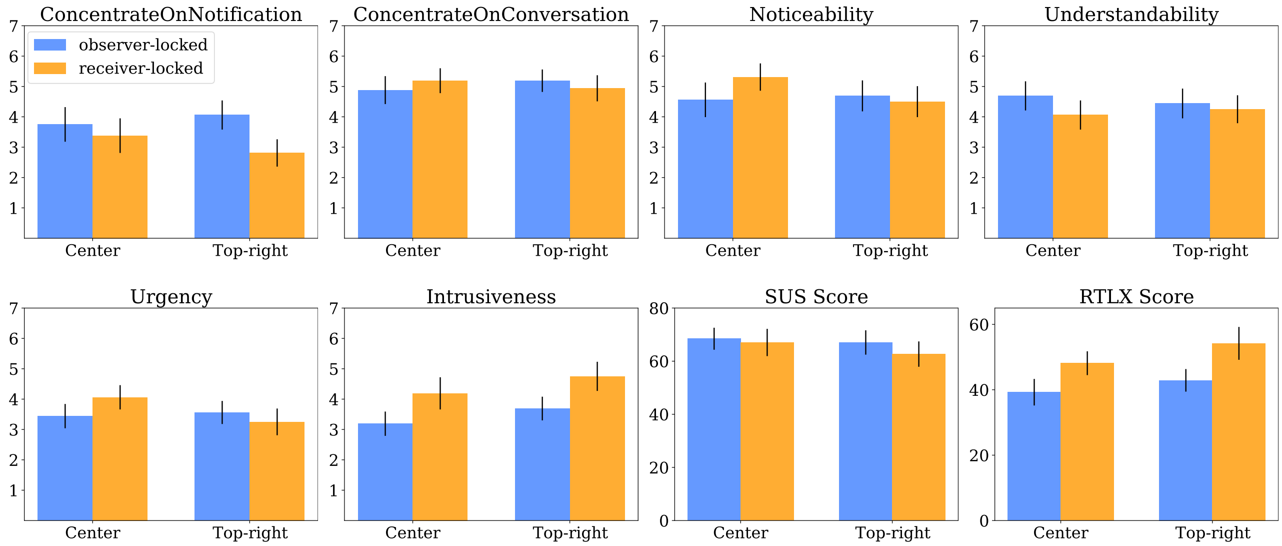


Figure 3: Diagrams displaying quantitative data collected from the *receiver*. Error bars show standard error.

	Position			Alignment			Position × Alignment		
	$F_{1,15}$	p	Partial η^2	$F_{1,15}$	p	Partial η^2	$F_{1,15}$	p	Partial η^2
ConcentrateOnNotification	0.008	.929	0.000	2.503	.134	0.143	0.813	.381	0.051
ConcentrateOnConversation	0.084	.775	0.005	0.014	.907	0.000	0.834	.375	0.052
Noticeability	0.759	.397	0.048	0.178	.679	0.012	1.265	.278	0.077
Understandability	0.019	.89	0.001	1.132	.304	0.07	0.118	.735	0.008
Urgency	6.464	.022	0.301	0.252	.623	0.016	6.927	.018	0.316
Intrusiveness	1.863	.192	0.11	6.412	.022	0.299	0.000	.983	0.000
SUS	1.027	.326	0.064	1.668	.216	0.1	0.447	.513	0.028
RTLX	2.461	.137	0.141	8.511	.011	0.362	0.232	.636	0.015

Table 1: ANOVA main effects and interactions for the quantitative data - *receiver*.

subjective data. We applied two-way repeated measured ANOVAs for the parametric data. For the nonparametric data, first, we applied the Aligned Rank Transform (ART) using the ARTool [24], as suggested by Wobbrock *et al.* [53]. Since we considered the dependent variables to represent conceptually distinct aspects that also might be differentially impacted by the conditions, we conducted multiple ANOVAs independently, as suggested by Huberty and Morris [20]. The statistical analysis of the quantitative data collected from the *receiver* and *observer* is summarized in Table 1 and Table 2, respectively.

4.1 Quantitative Data - *Receiver*

At the end of each session, all participants could remember at least three notifications that they received. On average, participants were positive about the *presentation* (*Median* = 5.5) and the *duration* (*Median* = 5) of the notifications. However, there was no statistically significant effect of our conditions on *presentation* ($F_{1,15} = 1.738$, $p > .207$, $F_{1,15} = 0.588$, $p > .455$, and $F_{1,15} = 0.526$, $p > .479$ for POSITION, ALIGNMENT, and POSITION × ALIGNMENT respectively) or *duration* ($F_{1,15} = 0.111$, $p > .743$, $F_{1,15} = 0.464$, $p > .506$, and $F_{1,15} = 0.672$, $p > .425$ for POSITION, ALIGNMENT, and POSITION × ALIGNMENT respectively) of the notifications.

Figure 3 presents the quantitative data that was collected from the *receivers*. For *concentrateOnNotification*, *concentrateOnConversation*, *noticeability* and *understandability*, there were no statistically significant main or interaction effects (all $p > .05$). For *urgency*, there were a statistically significant main effect of POSITION and an interaction effect of POSITION × ALIGNMENT. For the *receiver-locked* ALIGNMENT, displaying notifications in the *center* POSITION resulted in a higher level of perceived *urgency* ($M = 4.06$, $SD = 1.61$) compared with the *top-right* POSITION ($M = 3.25$, $SD = 1.77$). However, participants showed the opposite pattern while receiving notifications with the *observer-locked* ALIGNMENT ($M = 3.44$, $SD = 1.59$ and $M = 3.56$, $SD = 1.5$, respectively for *center* and *top-right*). Perceived *urgency* of notifications displayed in the *center* ($M = 3.75$, $SD = 1.61$) was significantly higher compared with the ones in the *top-right* ($M = 3.41$, $SD = 1.62$).

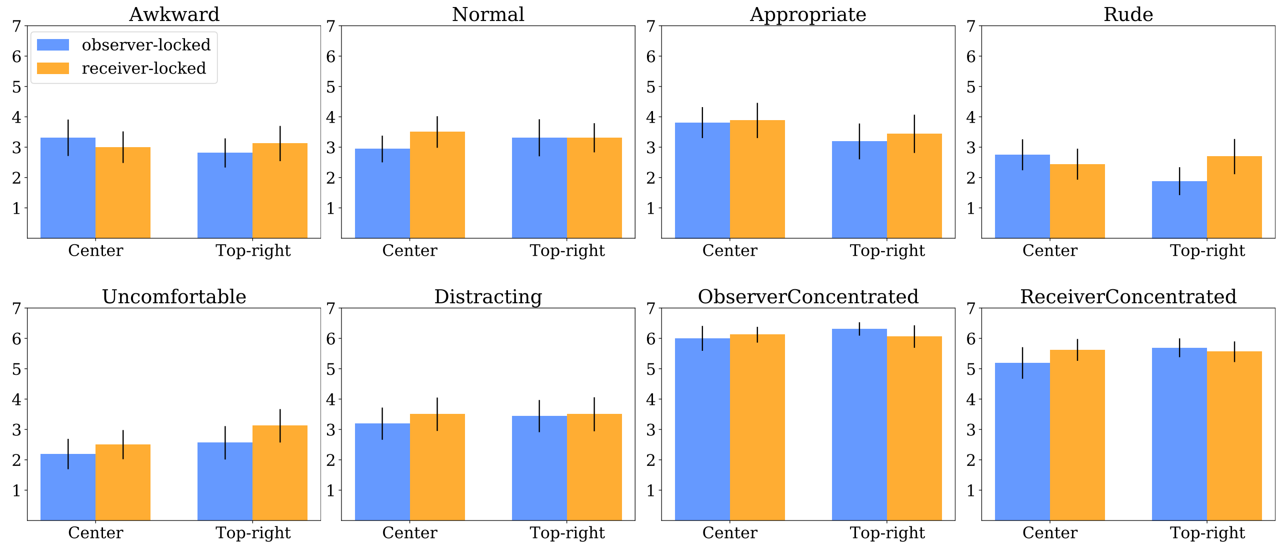


Figure 4: Diagrams displaying quantitative data collected from the *observer*. Error bars show standard error.

	Position			Alignment			Position × Alignment		
	$F_{1,15}$	p	Partial η^2	$F_{1,15}$	p	Partial η^2	$F_{1,15}$	p	Partial η^2
Awkward	0.273	.609	0.018	0.059	.812	0.004	0.288	.599	0.019
Normal	0.039	.844	0.003	3.655	.075	0.196	0.345	.565	0.022
Appropriate	2.225	.156	0.129	0.243	.628	0.016	0.062	.807	0.004
Rude	2.413	.141	0.139	0.122	.731	0.008	5.685	.031	0.275
Uncomfortable	4.153	.059	0.216	3.564	.078	0.192	0.451	.512	0.029
Distracting	0.616	.444	0.039	0.265	.614	0.017	0.219	.646	0.014
ObserverConcentrated	0.2	.661	0.013	0.055	.818	0.004	0.367	.553	0.024
ReceiverConcentrated	0.009	.922	0.000	0.05	.825	0.003	0.645	.434	0.041

Table 2: ANOVA main effects and interactions for the quantitative data - *observer*.

There was a statistically significant main effect of ALIGNMENT on the perceived *intrusiveness* of notifications. The participants perceived notifications presented with the *receiver-locked* (M = 4.47, SD = 2.02) ALIGNMENT as more intrusive compared to the ones with the *observer-locked* (M = 3.44, SD = 1.58) ALIGNMENT.

For the SUS score, no statistically significant main or interaction effects were found (all $p > .05$). However, for the RTLX score, we found a statistically significant main effect of the ALIGNMENT. Notifications displayed using the *receiver-locked* (M = 51.16, SD = 17.53) ALIGNMENT resulted in significantly higher RTLX score compared to the ones using the *observer-locked* alignment (M = 41.06, SD = 16.1).

4.2 Quantitative Data - *Observer*

Figure 4 shows the quantitative data that was collected from the *observer*s. For *Rude*, there was a statistically significant interaction effect of POSITION × ALIGNMENT. For the *center* POSITION, while displaying notifications using *observer-locked* ALIGNMENT (M = 2.75, SD = 2.05), *observer*s felt more rude compared with the *receiver-locked* ALIGNMENT (M = 2.44, SD = 2.03). However, results showed the opposite pattern while displaying notifications in the *top-right* POSITION (M = 1.88, SD = 1.82 and M = 2.69, SD = 2.33, respectively for *observer-locked* and *receiver-locked*). There were no other statistically significant main and interaction effects for the other scales used in the questionnaire for the *observer*s.

4.3 Qualitative Feedback

At the end of the study, two researchers conducted semi-structured interviews with both *receivers* and *observers* separately. We audio-recorded all interviews for later analysis. We transcribed the interviews literally while not summarizing or transcribing phonetically, as suggested by previous work [3]. Three researchers applied a simplified version of qualitative coding with affinity diagramming to analyze the interviews [17].

4.3.1 Receivers' Feedback. Overall, participants had a positive general impression of the study settings and the system, as they indicated that the social interaction was *pleasant* and *entertaining* (P1, P4, P6, P13, P15) and the system *good to be informed about notifications easily and without looking at the smartphone* (P2, P4, P9, P11, P14). However, 10 (62.5%) participants commented on the distracting hardware. 6 (37.5%) stated that they found the HoloLens heavy, while for 4 (25%) the headset was not comfortable. 2 (12.5%) participants stated that the HoloLens was heavy only at the beginning of the study. 8 (50%) participants indicated that receiving notifications during a face-to-face conversation does not entirely interrupt the conversation, but can divert attention from the discussion: *"The notifications were not totally annoying, but they could distract my attention from following the flow of the conversation"* (P16). *"If I see a notification, I will concentrate on it although I actually want to have communication"* (P14).

8 (50%) participants commented that it is impolite to read notifications during a face-to-face conversation: *"[It is] rude since the interlocutor does not know that one could read something and be distracted"* (P6). *"[It is inappropriate] not to look at the conversation partner as a notification was received"* (P2). However, 3 (18.7%) participants stated that it is appropriate to view a notification using AR glasses if it is very important.

Participants also compared a smartphone and AR glasses as a medium to view notifications during a face-to-face conversation. 7 (43.7%) participants preferred to view notifications on AR glasses rather than on a smartphone: *"AR glasses [would be for this purpose] less annoying [than a smartphone]. Because the communication partner does not notice that you read, and you do not have to interrupt anyone to read a short notification"* (P9). *"It is better [to view a notification] on AR glasses since you do not have to look away to read it"* (P15). However, 4 (25%) participants preferred to view notifications on a smartphone during social interaction: *"My conversation partner can explicitly see that I am viewing a notification at my smartphone and deal with it"* (P6). *"Smartphone is better to read notifications. The communication partner knows that one does not listen for a moment"* (P13). 5 (31.2%) participants indicated that they would prefer to read a notification neither on a smartphone nor AR glasses during a face-to-face conversation.

When providing feedback about notification positions and alignments, 12 (75%) participants stated that they would not prefer to receive notifications in the *top-right* POSITION with *receiver-locked* ALIGNMENT: *"While receiving these notifications, I lost eye contact with the communication partner"* (P12). However, 4 (25%) indicated that they do not favor the *center* POSITION with *observer-locked* ALIGNMENT as it was not possible to completely see the interlocutor's face. Notifications using the *center* POSITION with the *observer-locked* ALIGNMENT were the most preferred (8 participants) as there was no need to look away from the communication partner. While 6 (37.5%) participants preferred the *top-right* POSITION with the *observer-locked* ALIGNMENT, 2 (12.5%) favored the *center* POSITION with the *receiver-locked* ALIGNMENT.

7 (43.7%) participants stated that they would prefer to be informed about notifications than directly receiving it on the AR glasses: *"I would prefer to see a small icon and decide whether I want to read it or not"* (P5). *"Small indicator would be better. [It would be] better if I could decide when a notification should be displayed"* (P9).

4.3.2 Observers' Feedback. 5 (31.2%) participants stated that talking to someone wearing a HoloLens was only at the beginning unpleasant: *"With time, the AR glasses were no more so conspicuous. It was possible for me to get used to the HoloLens during our conversation"* (P23). 7 (43.7%) participants commented on the HoloLens that it did not negatively affect the conversation: *"The glasses were very conspicuous, but it did not disturb the conversation"* (P27). However, 4 (25%) participants found the AR glasses disturbing during the conversation since they could not clearly see the eyes of their communication partners.

We also asked *observers* if they noticed any activity with the AR glasses. 7 (43.7%) participants indicated that they did not recognize any activity of the *receivers* with the AR glasses. However, 9 (56.2%) participants discerned eye movements of the *receiver* without identifying the actual activity: *"Sometimes, my communication partner had looked to the side, but I do not know if he did something or if it simply was a normal behavior"* (P25). After answering this question, the interviewer explained that the participant with the HoloLens had been receiving notifications on the device.

5 (31.2%) participants indicated that it is appropriate to read notifications on AR glasses during communication: *"The glasses did not affect the conversation even if you know that your communication partner reads something simultaneously"* (P26). 6 (37.5%) participants commented on the limitation of the used AR glasses, which made the glasses not suitable for viewing notifications: *"If the glasses were not so big and heavy then it would be more appropriate than a smartphone because you do not have to look away"* (P22, P23, P30). 5 (31.2%) participants stated that AR glasses are not suitable to read notifications since the communication partner does not know if the person with the AR glasses is paying attention to the conversation.

5 (31.2%) participants indicated that they would rather receive notifications on a smartphone than on AR glasses: *"By looking at a smartphone one makes a conscious conversation break and the dialog partner knows that the other person does not listen to her for a moment"* (P36). *"It is not clear if the person with AR glasses is listening"* (P29). However, 8 (50%) participants stated that AR glasses are better to view notifications: *"With a smartphone, it is more annoying than AR glasses if one looks over and over at the device during a conversation. However, with AR glasses, the interlocutor does not notice it"* (P30). *"It is rude to look at a smartphone during a conversation because this causes interruptions"* (P24). For 3 (18.7%) participants viewing notifications on AR glasses was similarly rude as on a smartphone.

5 DISCUSSION

For the *receivers*, the study revealed significant main effects of POSITION and ALIGNMENT and an interaction effect of POSITION × ALIGNMENT. For the *receiver-locked* ALIGNMENT, the notifications in the *center* POSITION were perceived more urgent than the ones in the *top-right* POSITION. However, for the *observer-locked* ALIGNMENT, the notifications displayed in the *top-right* POSITION were considered slightly more urgent than the ones in the *center* POSITION. The qualitative feedback revealed that notifications using the *center* POSITION with *observer-locked* ALIGNMENT partly occlude the interlocutor's face and thus grab the attention. Using this combination of the ALIGNMENT and POSITION, participants could view both the notifications and the interlocutor simultaneously without being urged to look at the notification in another POSITION. However, the notifications using the *top-right* POSITION with *receiver-locked* ALIGNMENT result in the loss of eye contact with the communication partner.

The notifications using *receiver-locked* ALIGNMENT were considered more intrusive than the ones using the *observer-locked* ALIGNMENT. This could be explained by the fact that the notifications using this ALIGNMENT are displayed directly in front of the user. Consequently, the perceived task load to view notifications using *observer-locked* ALIGNMENT during a face-to-face conversation was lower than the ones using the *receiver-locked* ALIGNMENT.

Furthermore, our results suggest that in all POSITION and ALIGNMENT conditions, participants could similarly concentrate both on the notifications and the conversation. This is also supported by the fact that we did not find any significant difference in *concentrateOnNotification* and *concentrateOnConversation* values.

For the *observer*s, the results show that in all conditions, participants and their communication partners could similarly well concentrate on the conversation. Furthermore, participants found communicating with a person wearing AR glasses similarly *awkward*, *normal*, *appropriate*, *uncomfortable*, and *distracting*, regardless of the study condition. However, the participants felt slightly more rude when their communication partner was receiving notifications in the *center* POSITION using *observer-locked* ALIGNMENT compared with the *receiver-locked* ALIGNMENT. While receiving notifications in the *center* POSITION using *observer-locked* ALIGNMENT, a *receiver* was more urged to stare at the interlocutor's face and read the notifications, which is not suggested for the design of interaction mechanics for smart glasses [1]. On the other hand, as the notifications were presented in the *top-right* position, *observer*s felt more rude when the *receiver-locked* compared to *observer-locked* ALIGNMENT was used. As eye contact is an important element in everyday social interactions [1], this could be explained by the fact that *observer*s could notice the loss of *receiver*s' eye contact as the consequence of reading notifications displayed in the top-right of their direct field of view.

Through the qualitative results, we learned that augmenting users' vision with digital notifications during social interaction does not entirely interrupt the conversation. However, it might be impolite regarding the conversation partner as the interlocutor is not aware of notifications in AR glasses. Interestingly, some participants considered this unawareness positively. Compared to viewing notifications using smartphones, notifications in AR glasses might be less annoying for interlocutor as it does not require a user to hold the device and interrupt the conversation.

6 LIMITATIONS

The majority of both *receiver*s and *observer*s indicated that during social interaction, they would prefer to receive notifications on AR glasses rather than a smartphone. However, both *receiver*s and *observer*s commented on the limitation of the used AR glasses. As the AR glasses, we used a first-generation HoloLens, which is heavy and uncomfortable, as stated by our participants. Since we used only HoloLens as the AR glasses, we assume that AR glasses with better physical properties, as suggested by the participants, could make viewing notifications during social interaction more appropriate. However, future research is needed to test this assumption, as different AR glasses can affect the social acceptability.

Furthermore, during the study, participant pairs were sitting in front of each other and engaging in a conversation. They were told not to stand up or move during the conversation sessions. Despite this stationary study setting, we found significant effects of ALIGNMENT for both *receiver* and *observer*. Repeating the same study in a more dynamic setting (*e.g.*, the *observer* and *receiver* are talking while walking together) would probably reveal different results regarding the ALIGNMENT. However, future research is needed to determine this effect. Moreover, since the disruptiveness of notifications can be affected by its presentation, alert type, sender-recipient relationship, as well as the type, duration and importance of social interaction [32], future research is needed to investigate these effects while considering notifications on AR glasses.

For the study, we used notifications that were not collected from participants. To enhance the realism and allow participants to envision how their notifications would appear in AR, we used real notifications using commonly given names in the country of the study. Therefore, we assume that we decreased potential effects caused by not showing participants' notifications.

7 CONCLUSION

We investigated two positions (*center*, *top-right*) for notifications while aligning them relative to the user's field of view (*receiver-locked*) or with the conversation partner (*observer-locked*) using AR glasses during social interaction. We found that displaying notifications using the *observer-locked* alignment reduces the user's task load and perceived intrusiveness. Furthermore, while receiving notifications in the *top-right* position, the communication partners feel less rude when the notifications are aligned with them. Nevertheless, while receiving notifications in the *center* position, the communication partner feels slightly less rude when the notifications are displayed using *receiver-locked* alignment. Receiving notifications in the *center* position results in higher perceived urgency using the *receiver-locked* alignment. In contrast, notifications in the *top-right* position yield higher perceived urgency using the *observer-locked* alignment.

The results suggest that general notifications displayed on AR glasses should be presented with the *observer-locked* alignment during face-to-face communication. Notifications presented using this alignment are the least intrusive, and the required task load to view the notifications and engage in the conversation simultaneously is the least. The qualitative results showed that participants were not agreed on a single notification position. Thus, users should also be enabled to specify their preference for the notification position with the *observer-locked* alignment. Only very important notifications should be displayed with the *receiver-locked* alignment using the *center* position. Displaying notifications in this combination will be perceived as both urgent and intrusive. The users would accept their negative impact to ensure receiving critical notifications. However, users should be able to define which notifications are urgent.

In this work, we only investigated receiving notifications using AR glasses. However, future work that enables users also to reply to notifications in AR is needed. Furthermore, as we did our study while only two people were communicating, future work should investigate AR notifications during social interaction in a more crowded environment. As our participants proposed to display only essential notifications in AR glasses or to inform about notifications in AR glasses without showing the content, future work should investigate various approaches to notify users about incoming messages using AR glasses.

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