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Improving Collaboration in Augmented Video Conference using Mutually Shared Gaze

Gun Lee[1]†, Seungwon Kim[1], Youngho Lee[2,1], Arindam Dey[1], Thammathip Piumsomboon[1], Mitchell Norman[1] and Mark Billinghurst[1]

[1]Empathic Computing Laboratory, School of ITMS, University of South Australia, Australia
[2]Mokpo National University, Republic of Korea

Abstract

To improve remote collaboration in video conferencing systems, researchers have been investigating augmenting visual cues onto a shared live video stream. In such systems, a person wearing a head-mounted display (HMD) and camera can share her view of the surrounding real-world with a remote collaborator to receive assistance on a real-world task. While this concept of augmented video conferencing (AVC) has been actively investigated, there has been little research on how sharing gaze cues might affect the collaboration in video conferencing. This paper investigates how sharing gaze in both directions between a local worker and remote helper in an AVC system affects the collaboration and communication. Using a prototype AVC system that shares the eye gaze of both users, we conducted a user study that compares four conditions with different combinations of eye gaze sharing between the two users. The results showed that sharing each other's gaze significantly improved collaboration and communication.

CCS Concepts

•***Human-centered computing*** → ***Mixed / augmented reality;*** *Computer supported cooperative work;*

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1. Introduction

Using live video conference is becoming a common activity enabled by mobile technology for collaborating with others remotely. A person can live stream video of their workspace to a remote person who can help completing a real world task. With a local worker wearing a head-mounted display (HMD) and a camera, remote helpers can watch through the local worker's eyes and give advice. In addition to verbal communication, remote helpers could also provide feedback using visual cues. For example, the remote helper can use a mouse (or touch screen) to control a virtual pointer overlaid on top of the shared video, or draw annotations on the shared live video view that can be shared back with the local worker. Such a system could be useful in many remote collaboration applications such as providing technical support [BHKS98].

Kraut et al. [KFS03] found that using a HMD and camera to share visual information is one of the most useful resources for collaboration on physical tasks. Fussell et al. [FKS00] also found a positive effect of using shared visual cues studying the effects of shared visual context on collaborative work. Similarly, Siegel et al. [SKJC95] found that head-worn remote collaborative systems had a positive impact on maintenance tasks. In these prior works, the remote user was able point in the local user's view using desktop interface. In our research we are interested in the benefit of sharing gaze cues between the two users, in addition to the visual cues used in these systems.

Using eye tracking technology [Duc07], the gaze of a person can be identified to track where their attention is directed. Earlier studies have investigated sharing gaze in desktop [CHN*10] or immersive virtual environments [NCD*10], but our research focus on sharing gaze cue in the real world task using an Augmented Video Conferencing (AVC) system that combines Augmented Reality (AR) technologies with video conferencing. There is also earlier work focused on sharing the gaze of one of the users in an AVC system, such as the local worker [GLB16] or the remote helper [HYS16]. They have found that sharing gaze helps collaborators feel more connected and provides an important indication of user attention. However, to our best knowledge, there is no investigation on AVC systems that share the gaze of both users with each other. So the primary goal of our research is to investigate how sharing gaze cues from both users could affect the collaboration and communication between the two users. This work makes the following novel contributions:

- It is one of the first proof of concept remote collaboration AVC systems that share eye gaze between both local and remote users.
- It is one of the first user studies exploring the effect of sharing eye gaze cues in both directions and comparing their effect on the collaboration and communication.

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† gun.lee@unisa.edu.au

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2. Related Work

There are many prior research in using HMDs and Head-Worn Cameras (HWC) for remote collaboration, for example Shared-View [IKTM90] being one of the earliest system using such configuration. Many researchers have shown that enabling a remote helper to see what a local worker is doing and providing visual feedback significantly improves remote collaboration on physical tasks [BKS99] [FKS00] [KFS03]. Recently, AR techniques have been developed to align virtual feedback cues with the real world [GNTH14] [KLSB14]. However, a limitation of these systems is that neither of the users knows exactly where the other person is looking within the shared video view. The remote helper may be looking at a different part of the live video view than the local worker, and so they may have collaboration problems.

Gaze is an important cue for showing attention and mutual understanding in face-to-face collaboration. Similarly, in remote collaboration, gaze can be useful for creating shared focus and attention on objects of interest [MD95]. There has been some previous work on sharing gaze cues in remote collaboration in a desktop computer setting [SB04] [LMDG16] [MHPV13]. For example, Muller et al. [MHPV13] developed a system where two remote users can use a desktop puzzle application together, and found that participants received their instructions more clearly from partners when gaze information was shared in addition to speech. Brennan et al. [BCD*08] also found similar results that sharing a person's focus of attention with the other's through gaze cues could significantly improve task performance. Overall, gaze provides an excellent cue for inferring user attention and improving collaboration in a desktop interface.

A number of researchers have also explored using head-worn eye tracking to enable sharing gaze in collaboration on a physical task. Fussell et al. [FSK03] attached an eye tracker to an HWC to enable a local worker to share gaze cues with a remote helper. In a user study they found that sharing eye gaze information produced no performance improvement over using speech only, however in a follow-up study they found that the focus of attention can be predicted from monitoring eye gaze in a remote collaboration task, which could be beneficial [OOF*08]. In these cases the local worker only wore an eye-tracker and camera but without an HMD, so the remote helper could not give visual feedback.

Gupta et al. [GLB16] proposed a system combining a HMD with a HWC and an eye tracker that enables the user to share his or her gaze with a remote helper who can use a virtual pointer. In a user study they found that the use of eye tracking and a pointer together significantly improved both co-presence and overall task performance. Their system was only sharing the local worker's gaze but not the remote helper's. On the other hand, there are a couple of researches on sharing the remote helper's gaze. For example, Higuch et al. [HYS16] and Barathan et al. [BLBL17] recently explored showing remote helper's gaze cues to the local worker using a projection display or a HMD.

In summary, there has been significant work using HMDs and HWCs for remote collaboration, showing the benefit of sharing a remote view in collaboration on physical tasks. Desktop experiments have confirmed the value of sharing gaze for remote collaboration, and there are a few examples of sharing gaze from one participant in a HMD/HWC system. Compared to prior work, our research investigates sharing gaze in both directions in a AVC based remote collaboration.

3. Prototype AVC System for Sharing Gaze

We developed a prototype system for investigating the benefit of mutual gaze sharing in AVC where a local worker shares his or her workspace while the remote helper watches the shared video and give advice through verbal communication. A camera attached to the HMD captures the workspace of the local worker and streams the video to the remote helper's desktop. The HMD also shows the video captured from the camera so that the two users shares the same view of the local worker's workspace (see Figure 1).

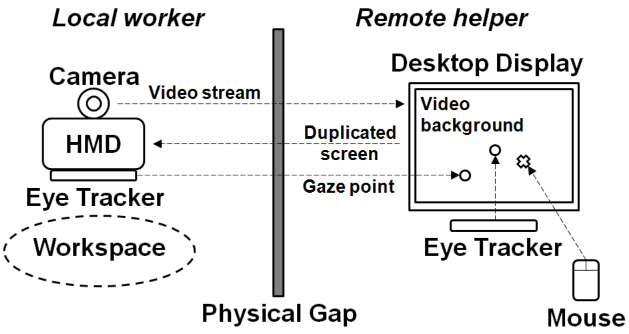

Figure 1: *Prototype system configuration.*

The shared video can be augmented with visual cues to provide additional information that helps the communication between users (see Figure 2). For example, in order to enable the remote helper to point at certain objects in the shared video, the prototype system overlays a mouse pointer (semi-transparent red 'x' mark) onto the shared video, controlled by the remote helper. In addition to the mouse pointer, the prototype system uses eye trackers, both in the local worker's HMD and on the remote helper's desktop monitor, to visualize the gaze points (semi-transparent circles) of the users, helping them to understand each other's focus in the shared workspace.

The prototype system was implemented on a desktop computer with an Intel Core i7-6700 3.4GHz CPU, 8GB RAM, and Nvidia GeForce GTX 950 GPU, running Microsoft Windows 10 operating system. An HTC Vive (`https://www.vive.com`) HMD was used for the local worker which has a wide field-of-view and includes a wide field-of-view USB camera to capture the real-world view. We used a 22-inch desktop monitor as the remote helper's display. Both displays were connected to the same computer running an application we developed using Unity 3D game engine (`https://unity3d.com`; v5.5.1f1). The application captured the video from the camera and displayed it on the HMD, textured onto a rectangular polygon placed perpendicular to the virtual camera representing the user's view. The system did not provide stereoscopic image of the real-world view, but we adjusted the viewing parameters to make the video see-through view as natural as possible. To achieve this, we manually calibrated the position of the

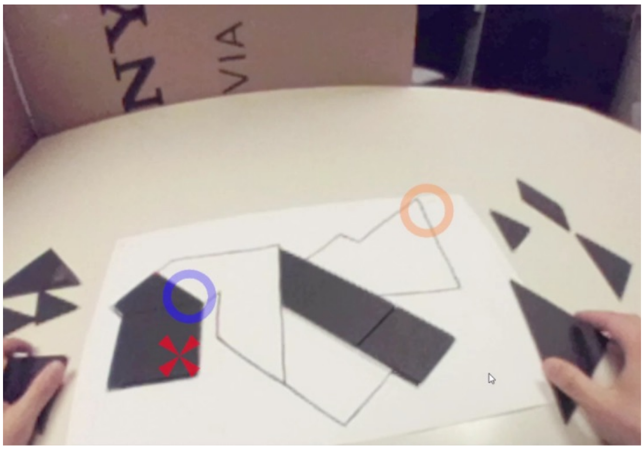

Figure 2: *A screen capture image of the prototype software showing visual cues (red x: mouse pointer, blue circle: desktop user's gaze, orange circle: HMD user's gaze) overlaid on shared video of the real world view.*

video plane relative to the virtual camera so that the real-world view shown in the HMD is similar to the view seen with the user's natural eyes in terms of viewing direction and the field of view. While using an optical see-through HMD could be an alternative, we chose this configuration to provide wide field of view to the user which would be important to investigate the benefits of sharing gaze. For tracking the local worker's gaze we attached a pair of Pupil Labs (`https://pupil-labs.com`) eye tracking camera (120Hz update rate) inside the HTC Vive and used the Pupil Capture software that streamed the eye tracking results to our application. For tracking the remote helper's gaze, we used Tobii EyeX (`http://tobiigaming.com/product/tobii-eyex`).

4. User Study Design

To investigate the effect of sharing eye gaze between the local worker and the remote helper, we designed and conducted a user study where participants were asked to perform a collaborative task under different combinations eye gaze sharing. The study used a 2x2 factorial design (see Table 1) where the two independent variables were (R) whether the remote helper's eye gaze is shared or not, and (L) whether the local worker's eye gaze is shared or not. Based on these two factors we defined four conditions: no gaze shared (R0L0), only local worker's gaze shared (R0L1), only remote helper's gaze shared (R1L0), and both users' gazes shared (R1L1). All four conditions included verbal communication, and also the remote helper's mouse pointing as a basic visual cue shared in an AVC system.

4.1. Experimental Setup

Figure 3 shows the setup used in the study. Similar to the setup used in prior work [GLB16] [KLSB14], the participants were seated at desks separated by a divider. On one side of the divider was the local worker wearing an HMD, and on the other side was the remote helper, so they could not see each other, but were still able to hear and talk to each other, ensuring reliable verbal communication.

Table 1: *Experimental conditions.*

Factors		(R) Remote Helper's eye gaze	
		Not shared	Shared
(L) Local Worker's eye gaze	Not shared	R0L0	R1L0
	Shared	R0L1	R1L1

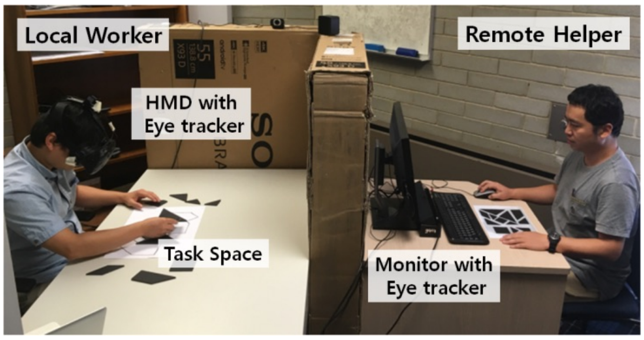

Figure 3: *Experimental environment.*

4.2. Experimental Task

Prior user studies in one-directional gaze sharing [GLB16] [HYS16] [BLBL17] mostly focused on a remote instruction scenario where the remote helper provides most of the guidance. In comparison, in this study we were interested in a mutual collaboration task [KLSB14] with equal discussion between the users. Following an example from prior work [KLSB14] we chose solving a Tangram puzzle (see Figure 4) as the experimental task. It uses flat puzzle pieces in various shapes that the player has to put together to form a particular shape presented by its outline or silhouette.

We customized the puzzle to include twelve pieces in different shapes from the traditional version to prevent the task being biased by the participant's prior experience. We found from a pilot test that task performance has a very high variance, due to differences in subject's spatial ability, prior experience. So we let participants spend a fixed amount of time collaborating with each other to solve the puzzle as much as possible, rather than measuring task completion time.

4.3. Experimental Procedure

The study started with participants reading the information sheet, signing a consent form, and filling out a demographic questionnaire. The researcher then further explained the setup including the prototype system and the task. To get familiarized with the task, participants were asked to solve a sample Tangram puzzle face-to-face.

The study was divided into two sessions, and the participants swapped their roles (local or remote user) between the sessions. At

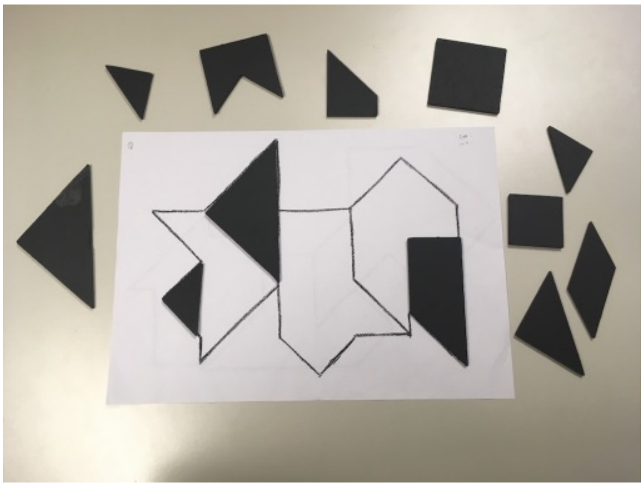

Figure 4: *Customized Tangram puzzle for task.*

Table 2: *Subjective rating questions (answered on a scale of 1: Strongly Disagree 7: Strongly Agree, except for Q15, 1: Very Difficult 7: Very Easy).*

Q#	Rating statement
Q1	I enjoyed the experience.
Q2	I was able to focus on the task activities.
Q3	My partner and I worked well together.
Q4	I was involved in the task activities.
Q5	My partner was involved in the task activities.
Q6	I was able to express myself clearly.
Q7	I was able to understand my partner's message clearly.
Q8	My partner's message was unclear to me.
Q9	I felt connected with my partner.
Q10	I felt I was present with my partner.
Q11	My partner was able to sense my presence.
Q12	I understood where my partner's focus was on.
Q13	My partner understood where my focus was on.
Q14	I was following my partner's focus.
Q15	Overall, the collaboration was ... (1: Very Difficult 7: Very Easy)

the beginning of each session, the participants were equipped with the prototype (i.e. wearing the HMD and calibrating the eye trackers) and were given a chance to get familiarized with the interface provided for his/her role. Each session included four experimental trials with each trial assigned with one of the four conditions. The order of the conditions tried by the participants was counter balanced based on the balanced Latin-square design method.

In each trial, participants were given approximately three and a half minutes to solve a puzzle while collaborating with each other. Eye tracking calibration was conducted as required, and each condition started with a new puzzle to solve. If the participants solved the puzzle too early, they were provided with another puzzle to solve for the rest of the time.

At the end of each trial participants gave subjective feedback on the given condition by answering a set of 7-point Likert scale rating questions (see Table 2) about various aspects of the quality of collaboration and communication. The rating questions were adopted from prior work [GLB16] [KLSB14] [BLBL17]. At the end of each session participants ranked the four conditions based on their preference and completed the System Usability Scale [Bro96]. The questionnaires also included open questions to collect qualitative feedback on each condition and at the session end.

Overall, the whole user study took about 2 hours, including introduction, setup, two sessions of four trials of experimental task under different conditions, answering questionnaires, and debriefing at the end of the user study.

5. Results

We recruited 16 participants in pairs (13 male and 3 female) from 23 to 45 years old ($Mean = 31.8$; $Std.Dev. = 5.6$). Except for one pair, all the participants knew their partners prior to the experiment (e.g. friends or colleagues). All participants had used video conferencing software at least a few times a year, while many of them ($N = 9$) used it several times a month. All participants had prior experience of using AR and were familiar with the technology, rating 4 or higher ($M = 5.9$, $SD = 1.0$) on a 7-point rating scale (1: novice 7: expert). More than half of the participants ($N = 10$) had prior experience of playing with Tangram puzzles.

5.1. Subjective Rating on Collaborating Experience

In each condition, participants rated the collaborative experience in various aspects (see Table 2). For factorial analysis of the rating results we used a Repeated-measure ANOVA ($\alpha = .05$) with Aligned Rank Transform (ART) [WFGH11]. First we look at the overall results before looking into the individual rating items. The rating items had very high internal consistency (with the scale reversed for Q8). Cronbach's α was 0.938 including all items, and ranged between 0.930 and 0.943 when one of the items were deleted. As an overview of rating results on the collaborative experience, we aggregated the ratings into a single scale ranging from 1 to 7 by taking an average of all items with the scale reversed for Q8. Figure 5 summarises the results.

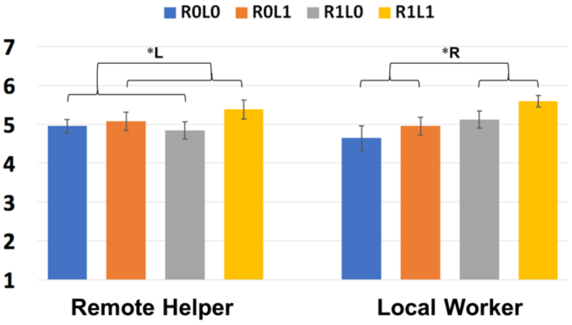

Figure 5: *Results of aggregated rating scale on collaborative experience (whiskers: S.E.; *: significant factor).*

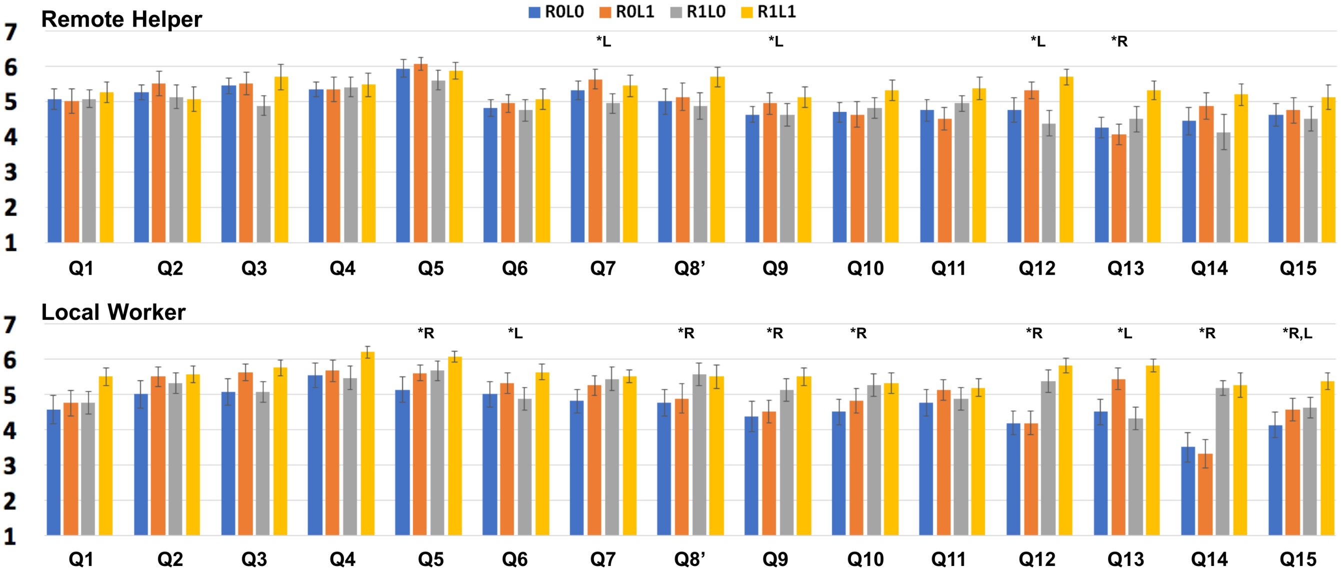

Figure 6: *Results of 7-point Likert scale rating questions (1: Strongly Disagree 7: Strongly Agree, except for Q15 which used 1: Very Difficult 2: Very Easy; the scale for Q8 is reversed; whiskers: S.E.; *: factor with significant effect.*

The results show that for the remote helpers, sharing the local worker's gaze had significant positive effect on the collaborative experience ($F(1,15) = 6.084$, $p = .026$) while sharing the remote helper's own gaze had no significant effect ($F(1,15) = 0.268$, $p = .612$). There was no significant interaction between the two factors ($F(1,15) = 1.646$, $p = .219$). In contrast, for the local workers, sharing the remote helper's gaze had a significant main effect ($F(1,15) = 17.772$, $p = .001$) yet sharing the local worker's own gaze had no significant effect ($F(1,15) = 2.535$, $p = .132$). There was no significant interaction effect ($F(1,15) = 0.019$, $p = .892$) found.

The results of the individual rating questions are summarized in Figure 6. Sharing local worker's eye gaze had a significant positive effect mostly on remote helpers' rating, while sharing the remote helper's eye gaze had a significant effect on local workers. We found no significant effect of sharing eye gaze on most of the questions related to task experience, including, enjoying the experience (Q1), being able to focus on the task activities (Q2), working well together (Q3), and being involved in the task activities (Q4). However, the results of Q5 indicated that sharing the eye gaze of the remote helper had a significant positive effect ($F(1,14) = 7.424$, $p = .016$) on the local workers' perceived involvement of their partner.

Regarding the questions on the quality of communication, local workers felt being able to express themselves significantly more clearly (Q6) with their eye gaze shared ($F(1,15) = 5.688$, $p = .031$), while from the remote helpers' perspective no significant main effect was found. Remote helpers rated significantly higher ($F(1,15) = 4.989$, $p = .041$) on Q7 indicating they were able to understand their partner's message more clearly when the local worker's gaze is shared. Rating results of Q8 indicated the remote helper's message was perceived more clearly by the local workers with the gaze shared ($F(1,15) = 4.657$, $p = .048$).

For the co-presence questions, sharing each other's gaze had a significant positive effect on both remote helpers ($F(1,15) = 4.961$, $p = .042$) and local workers ($F(1,15) = 13.666$, $p = .002$) feeling connected with their partner (Q9). Local workers felt their partner's presence (Q10) more when the remote helper's eye gaze was shared ($F(1,15) = 10.012$, $p = .006$), yet no significant effect was found on the remote worker's side. No significant effect was found for Q11.

Sharing of eye gaze most prominently affected the rating results of the focus related questions. The results clearly show that both remote helpers ($F(1,15) = 8.398$, $p = .011$) and local workers ($F(1,15) = 18.836$, $p = .001$) better understood where their partner's focus was on (Q12) when each other's eye gaze was shared. In the same way, participants felt their partners better understood their focus (Q13) when their own gaze is shared (remote helpers: $F(1,15) = 5.767$, $p = .030$; local workers: $F(1,15) = 32.082$, $p < .001$). Moreover, sharing the remote helper's eye gaze significantly increased the local user following (Q14) their partner's gaze ($F(1,15) = 19.265$, $p = .001$).

To the local workers, sharing either of their own ($F(1,15) = 4.560$, $p = .049$) or their partner's ($F(1,15) = 6.695$, $p = .021$) eye gaze made them feel that the collaboration was easier (Q15), yet the remote helpers did not perceive significant difference.

After the participants had tried the four conditions in one of the roles in each session, they were asked to rate on a 7-point Likert scale (1: Strongly Disagree - 7: Strongly Agree) asking if sharing the eye gaze improved collaboration. Figure 7 shows the average rating on these questions. Participants mostly agreed that sharing eye gaze improved collaboration with the average rating mostly being above the neutral value (4). A one sample Wilcoxon Signed Rank test ($\alpha = .05$) showed that the remote helpers felt sharing the local worker's eye gaze improved collaboration by rating significantly higher ($Z = 3.022$, $p = .003$) than the neutral value, but not for sharing her own eye gaze ($Z = 1.754$, $p = .079$). On the other hand, the local workers agreed sharing the remote helper's gaze improved collaboration ($Z = 2.508$, $p = .012$), as well as sharing his own eye gaze ($Z = 2.170$, $p = .030$).

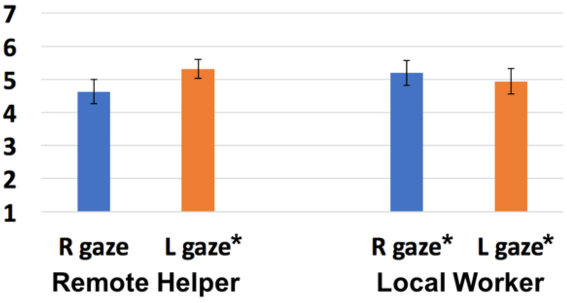

Figure 7: *Rating if gaze sharing improved collaboration (whiskers: S.E.; *: significantly different from 4).*

5.2. Ranking

At the end of each session, participants were asked to rank the four conditions based on their preference (see Figure 8). Overall, the condition sharing gazes from both the remote and local users were ranked the highest, while the condition with no gaze shared ranked the lowest. Participants tended to prefer their partner's gaze being shared more than sharing their own gaze. A Friedman test ($\alpha = .05$) showed the conditions were ranked significantly different by remote helpers ($\chi^2(3) = 20.625$, $p < .001$), and by the local workers ($\chi^2(3) = 11.925$, $p = .008$). A post-hoc pairwise comparison was conducted using Wilcoxon Signed Rank tests with Bonferroni correction ($\alpha = .0083$). The results showed the remote users preferred R1L1 condition significantly more than the R0L0 ($Z = 3.143$, $p = .002$) and R1L0 ($Z = 3.350$, $p = .001$) conditions. They also preferred R0L1 condition significantly more than R0L0 condition ($Z = 3.624$, $p < .001$). For local users the results showed significant difference only between R1L0 and R0L0 conditions ($Z = 2.728$, $p = .006$) with participants preferring R1L0.

5.3. System Usability Scale

To check the usability of the prototype, we asked the participants to fill out the System Usability Scale [Bro96] at the end of each session. The average SUS score of the desktop interface on the remote helper's side was 77.7 ($SD = 11.3$) and HMD interface on the local worker's side was 72.7 ($SD = 13.6$) which both are in the range of 'good' and acceptable usability [BKM09].

5.4. Observation and Qualitative Feedback

Solving a Tangram puzzle collaboratively involved several steps, including searching for a piece, showing or receiving an idea about where it could be placed, physically manipulating the piece, and checking if the placement is correct. In the searching step, both users looked at pieces individually, and they mostly had separate viewpoints. They used the shape and size of pieces to find an edge that matched between a piece and the outline of the target shape.

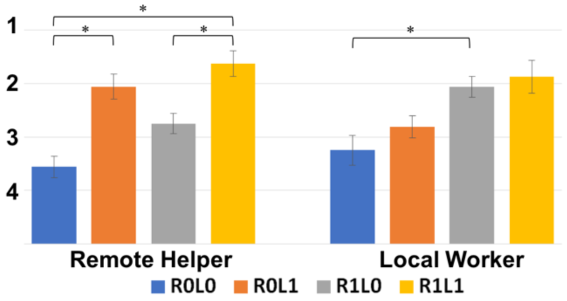

Figure 8: *Results of ranking (1: Best 4: Worst; whiskers: S.E.; *: statistically significant difference).*

While the searching step was mostly conducted individually, the rest of the steps were shared by both participants. When local workers found a proper piece and they moved it, some local workers verbally explained their manipulation (e.g. 'it can go here'). When the local workers started to manipulate a piece, the remote helpers easily recognized it and quickly changed their focus from searching to watching the movement or listening (receiving the idea), and paying attention to their partner.

When remote helpers suggested an idea, local workers paused, and paid attention to the remote helper explaining the idea using mouse pointer and gaze. In the interview, both remote and local users reported that the mouse pointer was very useful for communication. We observed that the remote helpers used the mouse pointer mainly for deictic purpose combined with verbal communication. They said 'this' or 'here' in combination with mouse pointing to indicate a puzzle piece. The eye gaze from the remote helper was also used for deictic purpose as the mouse pointer. For example, one of the remote helper participants mentioned that he pointed to objects with his gaze (by looking at them) and a local worker participant commented that he easily knew which piece his partner was interested in looking at his gaze. We observed a few remote helpers not using their mouse pointer much, and instead using their gaze to point at a puzzle piece or an area of interest. In such cases, local workers mostly watched and followed the remote partnerâĂŹs gaze instead of looking for the mouse pointer.

When local workers received a message from the remote helper on how to place a piece, there were cases where the local worker was not sure about how to orient the puzzle piece. In most of such cases, remote participants relied on verbal description to specify the orientation, such as, saying 'turn it clockwise' or 'flip it'. A remote helper commented that the system could be improved with addition of visual cues for describing the orientation of pieces. Once the local worker placed the puzzle piece, participants checked with each other if it looks correct.

We found two main differences between the mouse pointer and eye gaze. First, using gaze was faster than mouse pointer. A local worker commented that the mouse input was slower and another local worker said that he could predict which piece his partner would point with the mouse as the partner's eye gaze moved faster and was already on the piece before the mouse pointer got there. Similarly, some of the remote helpers mentioned that they could see what the next step will be with the eye gaze cue. Second, the eye gaze cue was always shown on the shared live video while the mouse pointer only appeared when the mouse left button was pressed. A remote helper mentioned that the mouse pointer would be more useful if it was always shown like the eye gaze, without needing to press down the button. A pair of participants commented that they could see the trail of partner's thought when they kept watching the partner's gaze.

At the end of each session, participants were asked a set of open questions. Answers given to the question asking what they liked about the system showed that sharing gaze was more useful on the local worker's side. Ten (63%) participants mentioned sharing gaze was useful when participating on the local worker's side, while only five (31%) participants mentioned it when on the remote helper's side. The mouse pointing was perceived useful more to the remote helper's side with seven (44%) participants mentioning it, compared to only two mentioning it on the local worker's side. When asked what could be improved in the system, local workers answered the quality of the video see-through HMD needs improvement (e.g., resolution of the camera, lack of stereoscopy) as many of them (10 out of 16) felt lack of depth perception and motion sickness. Five participants when on the remote helper's side mentioned it would be good to be able to draw annotations in addition to pointing. Another common feedback on how to improve the system was to hide the user's own gaze as it becomes distracting in certain cases, mentioned by four participants.

6. Discussion

The results showed that sharing eye gaze cues had the most prominent effect on improving the awareness of where the partner is focusing on (Q12 and Q13) for both remote and local users. Sharing the remote helper's eye gaze allowed local workers to follow their partner's focus (Q14).

The effect of sharing the remote helper's eye gaze was more prominent than sharing the local worker's eye gaze. When the remote helper's eye gaze is shared, the local workers felt their partner was more involved (Q5), their partner's message was clearer (Q8), and their partner's presence being more prominent (Q9 and Q10), resulting in easier collaboration (Q15). On the other hand, with sharing the local workers' eye gaze, the local workers themselves felt being able to express more clearly (Q6), while the remote helpers felt being able to understand the partner's message more clearly (Q7) and more connected with their partner (Q9). Overall, the effect of sharing the gaze of the local worker was less prominent compared to prior work [GLB16]. We postulate that the type of task might have had strong influence. Prior work used a remote instruction task which also included a subtask that divided users' attention, while our study focused on mutual collaboration which is more explorative.

In general, participants appeared to prefer and value more seeing their partner's gaze compared to sharing his or her own gaze (see Figure 7 and 8). Some of the participants mentioned seeing his/her own gaze was distracting time to time, and suggested showing it only to their partner. Some others mentioned even seeing their partner's gaze was distracting in certain times when they wanted to focus on their own task. It is also interesting that the local workers still considered sharing their own gaze as useful for improving the collaboration, while the remote helpers did not (see Figure 7). This also reflects the results of the local workers feeling the collaboration easier (Q15) with either of the gaze shared, yet the remote helpers not perceiving a significant difference.

Results on the system usability suggest there is room for improvement in the prototype system, especially the HMD interface on the local worker's side. One of the common problems participants had when using the HMD interface was taking time to adjust and calibrate eye tracking cameras inside the HMD. Developing a technique to make the calibration process easier would increase the usability. Another common problem reported was lack of depth perception. For tasks requiring larger movements, it could be necessary to provide better depth perception cues through using stereoscopic camera. This could be also combined with 3D gaze tracking, as explored in single user applications [PLW08], or using an optical see-through HMD.

7. Conclusion and Future Work

In this research, we investigated the effect of sharing gaze between the local worker and remote helper in an AVC system especially focusing on a mutual collaboration scenario. We developed a prototype system that is equipped with a wide field-of-view HMD and camera on the local worker's side and a desktop interface on the remote helper's side. The prototype system also included eye trackers on both HMD and desktop monitor so that the eye gaze of both users can be shared with each other. Using the prototype we conducted an initial user study that showed that sharing gaze significantly improves the awareness of each other's focus, especially sharing the gaze of the remote worker prominently improving collaboration and communication.

For future work we plan to further investigate the benefit of gaze sharing with tasks that involves larger task spaces that require more physical movement for the local worker. Further investigating how sharing gaze improves task performance would be another aspect to continue. Exploring different designs of visualizing the shared eye gaze cues to enrich the communication and collaboration as in face-to-face collaboration [AC76] would be also an interesting topic to investigate. Finally, we also plan to look into using eye gaze cues in combination with other augmented visual cues, such as world fixed annotation or hand gestures.

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