VR, Gaze, and Visual Impairment: An Exploratory Study of the Perception of Eye Contact across different Sensory Modalities for People with Visual Impairments in Virtual Reality

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ABSTRACT

As social virtual reality (VR) becomes more popular, avatars are being designed with realistic behaviors incorporating non-verbal cues like eye contact. However, perceiving eye contact during a conversation can be challenging for people with visual impairments. VR presents an opportunity to display eye contact cues in alternative ways, making them perceivable for people with visual impairments. We performed an exploratory study to gain initial insights on designing eye contact cues for people with visual impairments, including a focus group for a deeper understanding of the topic. We implemented eye contact cues via visual, auditory, and tactile sensory modalities in VR and tested these approaches with eleven participants with visual impairments and collected qualitative feedback. The results show that visual cues indicating the gaze direction were preferred, but auditory and tactile cues were also prevalent as they do not superimpose additional visual information.

CCS CONCEPTS

• **Human-centered computing** → **Virtual reality**; **Accessibility technologies**.

KEYWORDS

visual impairment, social virtual reality, eye contact, assistive technology

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1 INTRODUCTION

As humans, we are constantly involved in social interactions, in which we communicate via non-verbal signals such as gaze. We direct our gaze at people we want to talk to or signal interest in certain objects. This flexible behavior which allows us to communicate through our gaze has an evolutionary origin and is most highly developed in humans among all primate species [11]. Following actions based on gaze directions is, for instance, more pronounced in humans than in other primates [23]. The experimenter's head direction or eye movements were manipulated to see what great apes and human infants were more likely to refer to. Great apes tend to follow the head direction and human infants are more likely to follow the gaze direction. Put shortly, we humans have the prerequisites to communicate through gaze.

According to the sequential functional model of non-verbal exchange, our gaze behavior conveys functions that can be classified into providing information, regulating interactions, expressing intimacy, social control, and service tasks [10, 18]. This mode of communication can pose a challenge for people with visual impairments and as a result, they often rely on other sensory modalities [4]. Eye contact during conversations is indeed important for people with visual impairments, despite being barely perceptible [20, 25]. Specifically, people with visual impairments use gaze to signal a willingness to receive information from their conversation partner, and they understand the importance of gaze for sighted individuals [25]. Further, the absence of gaze can result in communication disadvantages in conversations with sighted individuals, given that gaze may serve as a signal for turn-taking, thereby facilitating a more rapid conversation [20].

Since there are many design options in social virtual realities (VR), non-verbal cues such as eye contact can be enhanced to be made perceptible to people with visual impairments. In this work, we explore initial designs with visually impaired people. To this end, we implemented gaze cues across visual, auditory, and tactile modalities in VR, and tested them with eleven visually impaired users. The results of our exploratory study indicate that the use of the presented cues is positively perceived and can contribute to an improvement in the quality of conversation in social VR. Furthermore, participants expressed a preference for the visual cue which indicates the direction of the gaze. The findings of this study offer initial insights into how to convey gaze information during conversations in VR for people with visual impairments.

2 RELATED WORK

Our research builds on prior work from two domains: first, the transformation and augmentation of social interactions, specifically gaze behavior, and second, applications that assist individuals with visual impairments in VR environments.

A study by Bailenson et al. [3] used a VR environment to investigate the impact of the speaker directing their head and gaze towards two listeners simultaneously. Participants reported higher levels of agreement with the statement provided by the speaker but simultaneously perceived a lower sense of social presence. However, when gaze behavior is augmented, participants felt a higher social presence [22]. In a VR museum setting, the authors let participants move freely in small groups and mutual eye contact was represented by several small light pink bubbles. Bailenson et al. refer to this approach as decoupling representations from behavior [2]. The decoupling can also be used to make non-verbal cues or gaze behavior perceivable for people with visual impairments, as perceiving eye contact is important for people with visual impairments [20]. Krishna et al. [13] used focus groups to explore the challenges faced by people with visual impairments in perceiving non-verbal signals. The inability to effectively interact with sighted individuals in a group discussion was identified as a major issue. To enable the perception of eye contact, Qiu et al. [19] developed glasses connected to a wristband. The glasses simulate different eye behaviors seen by the sighted counterpart. The wristband gives tactile feedback to people with visual impairments when they are looked at by their sighted counterparts. The wristband was shown to improve the conversation quality for people with visual impairments. Further, the PeopleLens is another device developed specifically for blind children, designed to recognize individuals in the environment and indicate their gaze direction [17]. Although these devices were not designed for VR, they can be adapted for VR use cases.

There have been various proposals on how to increase the accessibility of VR for people with visual impairments [7, 24, 26, 27]. In a social VR setting, the area around a person with a visual impairment was divided, and various sounds based on the distance of the approaching person were triggered [7]. Other examples include a cane that provides physical resistance and realistic tactile and auditory feedback when touching objects in VR [26], a VR application that generates an environment entirely through sound for people with visual impairments to navigate [24], and tools such as magnification lenses and edge enhancement in VR [27]. While these studies proposed to aid people with visual impairments in navigating and exploring virtual environments, they do not provide assistance in direct social interactions within VR.

3 METHODS

3.1 Participants

We recruited 13 participants from a center of competence for blindness, visual impairment, and multiple disabilities in Germany. The center provides school education and vocational rehabilitation for individuals with the specified impairments. Two participants were excluded due to the presence of only mild myopia. The age of the remaining eleven participants (two female, nine male) ranged from 18–30 years (*mean* = 22.5, *SD* = 4), and the diagnosis can be seen in Table 1. The study was conducted in the center of competence over two separate days. P1 and P2 took part on the first day, and P3 through P11 participated on the second day in the test and in the group discussion. However, P5 was unable to participate in the group discussion. The participants were compensated with 12€ per hour and signed the informed consent form. We received approval by an independent ethics committee.

Table 1: Demographic information and diagnosis of the eye disease of the participants

ID	Gender	Diagnosis
P1	w	Cone dystrophy
P2	m	Nystagmus since birth
P3	m	Myopia, Nyctalopia
P4	w	Coloboma
P5	m	Anisocoria, Retinal detachment
P6	m	Cone dystrophy
P7	m	Nystagmus
P8	m	Keratokonus
P9	m	Retinitis pigmentosa
P10	m	Blind on left eye
P11	m	High Myopia

3.2 Design and Procedure

The prototype test was preceded by a 45-minute group discussion with eight participants (P3-P11, except P5). Five general questions were asked in the following order: (1) *How do you perceive social signals?*, (2) *How important is eye contact for you?*, (3) *What means eye contact for you?*, (4) *Have you ever felt disadvantaged because you cannot perceive gaze in a conversation or situation?*, (5) *How are you made aware of eye contact?* For the individual VR setup, a HTC Vive Pro Eye was used and the study was implemented with the game engine Unity®. The participants sat in a chair in front of a desk and were first questioned about demographic information and their diagnosis. Subsequently, we asked the participants the following questions: (1) question two from the group discussion, (2) *Do you always try to look your conversation partner in the eye?*, and (3) question four from the group discussion. The reason for asking the same questions was that participants might be less inclined to give their input in a larger group setting. Afterward, the participants mounted the VR goggles and picked up the controllers. The VR scene was embedded in a custom-made coffee house-like setup with lounges and tables (Figure 1a). The contrast and brightness in the scene were adjusted to the participants in each trial. In the VR scene, the participants sat on a sofa and a realistic avatar sat opposite them. We used an avatar and animation from the Microsoft Rocketbox [5]. Participants were told they were now in a coffee house in VR, talking to the avatar sitting across from them. The experimenter then presented the visual, auditory, and tactile cues to the participants in succession by pressing keys on a keyboard. Following that, each cue was presented individually, and the participants' opinions were collected by asking for their perception of the cue and to rate it using a 5-point Likert item (5 best). The study lasted about 30 minutes for each participant. During the group discussion and prototype

Figure 1: VR scene and visual cues. (a) shows the VR scene with an animated avatar sitting across from the participants. (b) Visual Ray cue that starts from the avatar's eyes and ends below the participant's head in VR. If the ray were to pass from eye to eye, it would obscure the entire scene for the participant. (c) Visual Flash cue briefly illuminates the scene with white light, while retaining the outline of the avatar's hair.

testing, audio was recorded with the consent of the participants and then transcribed.

3.3 Gaze Cues

A total of five different cues were presented, divided into two visual, two auditory, and one tactile. Using these initial cues, we can explore basic features for future design considerations.

Visual Cues. Two factors were considered: a cue that indicated the location of the conversation partner in addition to eye contact (Visual Ray), and a cue that indicated that one was looking without giving directions (Visual Flash). These two cues provide hints as to whether it is imperative to incorporate the direction in a visual cue or whether it is enough to have a cue (without indicating the direction) that signifies that someone is looking at the participants. The Visual Ray comprised a red-colored, high contrast ray that extended from the avatar's eyes to below the participants' head in the scene, and was displayed for a duration of two seconds (Figure 1b). The Visual Flash is shown in Figure 1c, wherein the entire scene is briefly illuminated with white light, except for a slight outline of the avatar's hair, for approximately 0.5 seconds. Participants were queried for their sensitivity or history of epilepsy prior to the initial presentation of the Visual Flash. They were also asked for their consent to display the cue before each subsequent presentation of the Visual Flash. No participant reported any issues related to epilepsy or discomfort following the presentation of the Visual Flash.

Auditory Cues. We incorporated two distinct types for the auditory cues, namely auditory earcons and auditory icons, derived from the domain of sonification [6]. Auditory earcons are a class of sounds that lack any association with real-world sounds, while auditory icons are sounds with real-world equivalents [6]. Our objective was to gain a preliminary understanding of whether there is a distinction in the perception of eye contact when spatial hearing is absent, solely based on the representation of the two types. For the Auditory Earcon, a single chime was used and played twice. The Auditory Icon consisted of two successive tones utilized to represent a typical blink from a cartoon movie, as eye contact does not inherently produce any audible sound.

Tactile Cue. Several studies have used the sense of touch as a substitute for vision in people with visual impairments [1, 8, 9, 12, 15, 19, 21]. Further, the sense of touch has already been used as a substitute for eye contact in people with visual impairment [19]. Our objective through the use of the Tactile Cue was to examine if the sense of touch is preferred over other sensory modalities. We used the VR goggles controllers for the Tactile Cue, which vibrated twice in succession.

4 RESULTS

Our findings were divided into two categories, group discussion and individual responses, and results from the prototype test of various gaze cues. Numerals in brackets indicate the number of participants who mentioned a specific theme.

4.1 Group Discussion and Individual Responses

Perception of Social Signals. Gestures are mostly recognizable (3), and P9 mentioned that he cannot perceive gestures due to his loss of peripheral vision. The recognition of facial expressions depends mostly on distance and lighting conditions (4).

The Importance of Eye Contact. Most participants answered individually that eye contact during a conversation is important for them (8). However, continuous eye contact is rather disturbing for P4 ("Constant staring is unpleasant"). P3 and P6 answered that eye contact is not as important and should only be made once in a while during a conversation. Eye contact is important to P8, as he was taught its significance from a young age and still values it, however, he only maintains eye contact when physically possible. P10, who has autism, reported that it is generally strange for him to look other people in the eye for an extended period of time. For him, it is like a kind of relaxation when he can look away for a short time. Additionally, P11 consistently attempts to establish eye contact with their conversation partner, as he has difficulty in conversations when eye contact is not maintained.

Meaning of Eye Contact. The participants answered with examples from their everyday life. P8 mentioned that there can be a lot of communication involved in eye contact, especially with people who have similar thought patterns. P10 said he thought of the looks from his parents with widened and trembling eyes, signaling he had done something wrong when he was younger, and P11 answered "For me, eye contact means respect. If the other person does not look at me during a conversation and I notice it, I stop talking to the person after a short time".

Perceived Disadvantage. All participants answered individually as well as in the group discussion that they did not feel disadvantaged. However, there are certain situations in which they have unpleasant feelings. For example, P2 said "I would not say disadvantaged in that sense. I always feel uncomfortable with people who do not know what kind of eye disease I have", P4 mentioned, "When people greet me and pass by me quickly and I do not know whether they have kept eye contact". P8 said when he was in school, he often had situations where classmates would tell him to look at them when he was talking to them. He also often received criticism when talking in a circle with several people because he could not look into the other person's eyes. He has learned to deal with it. Now he is still bothered by the fact that so much emphasis is still placed on eye contact during job interviews, for example. P9 explained that he cannot perceive people standing next to him because of his tunnel vision. In a group conversation, he tries to pay attention to who is speaking and then look at the person, but he does not know if other people resent that he sometimes does not look at his counterpart when they speak and it does not feel right to him either. It used to be exhausting for him, but he has now learned to turn his head more to compensate.

Awareness of Eye Contact. The participants recommended that in certain situations it would be helpful if in addition their names were mentioned, by a teacher in class. P4 meant when people walk by you quickly and just say hello, she has no chance to recognize the person.

Eye contact with Partner. This question was only asked individually, and participants reported that they always try to look at their conversation partner (9) (P4, "Yes, even though I know I am squinting" and P6, "Whether I meet the eyes of the other is another question"). Contrary, P3 does not always establish eye contact but instead focuses on the direction of the conversation partner's head.

4.2 Prototype Test

We report on the test with the participants' answers (summarized in Table 2), their Likert scale ratings, and the preferred cue.

Feedback Method: Visual Ray. The participants reported that they like the visual ray in general (9). The high contrast and the color red were also perceived as positive (3). P5 stated that "You cannot miss it [the Visual Ray]" and P6 said, "To signal that the other person is looking at me, it is convenient". In P9's retinitis pigmentosa disease, the visual ray helps to orient in a conversation ("You know exactly where to look, which is good for my tunnel vision. So I have a guide in which direction I have to look"). Further, P3 said he likes the visual ray, especially when talking to someone. For group conversations, it might be too much. However, for P7 and P10 the visual ray was too thick and therefore irritating.

Feedback Method: Visual Flash. The visual flash was well perceived only by one participant (P5, "Suddenly everything was white for a short time and then the perception was captured"). All other participants did not like the Visual Flash. P11, P1, P8, and P3 mentioned that problems with orientation and general glare sensitivity could occur. P6 felt reminded of the flash of a photo camera and P9 mentioned problems in a group discussion and several flashlights. P10 added that it would be more pleasant if only the furniture in the background turned white. Taken together, the Visual Ray (10) was favored over Visual Flash (1) as a gaze cue.

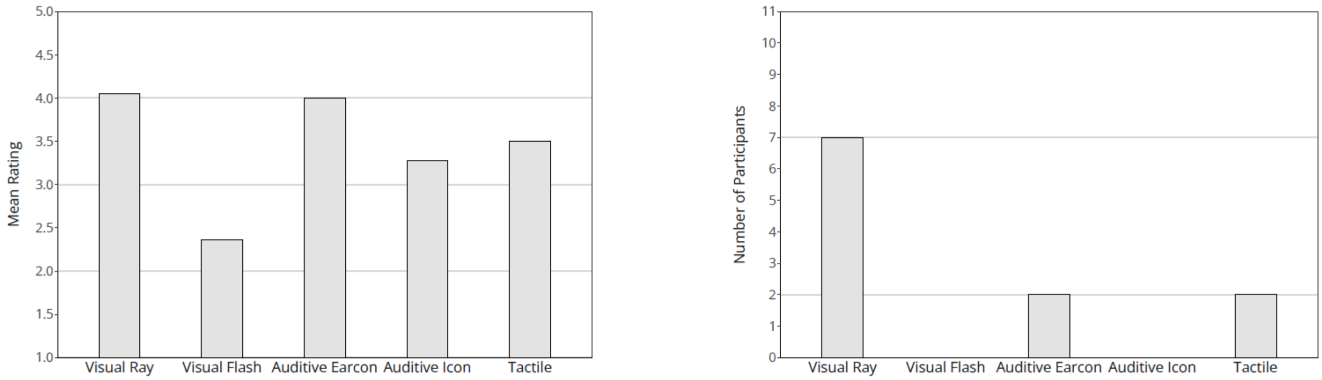
Table 2: Advantages and disadvantages of the proposed gaze cues as reported by the participants, along with the total number of participants who liked or disliked the cue.

Cue	Advantage	Disadvantage
Visual Ray	high contrast, indicates direction	overwhelming in group, obscures the scene
Visual Flash	captures attention	disorientation, sensitivity, origin of gaze not evident
Auditory Earcon	pleasant	other association, volume
Auditory Icon	salient	associated with games
Tactile	main channels of communication (visual and audio) free, attentive	atypical, origin of gaze not evident

Feedback Method: Auditory Earcon. The Auditory Earcon was well perceived by the participants (9). For example, P4 pays more attention to hearing because her vision is worse, and therefore an auditory cue is more comfortable. P6 and P8 liked the earcon but felt reminded of a parking sensor in the car and the auditory signal in the airplane to release the seat belts. P5 mentioned, "The sound is very good and not too loud and you know what is meant". Besides that, P2 did not like the sound because it is too quiet and could be overheard. He wants to focus on the conversation and not on any audio effects.

Feedback Method: Auditory Icon. The Auditory Icon produced mixed results among the participants, with some indicating that it was salient and just fit (5) while others reported that it was too playful (6). P2 reported that the auditory icon was more noticeable and P3 said "The tone fits very well through the comic eye blink sound". Contrary, it reminded P6 of a game and he does not like the blink as a tone. P8 mentioned, "The sound is too shrill for me". In summary, the Auditory Earcon (8) was generally viewed as more effective than the Auditory Icon (3).

Feedback Method: Tactile. The Tactile Cue was well-liked by the participants in general (8). P1, P5, and P7 answered respectively that it does not vibrate for too long and is not too strong, it is perceptible and increases attention as well as concentration on the conversation. For example, P2 said, "I think it is very good. Because I would not be distracted visually or auditorily during the conversation and the vibration is sufficient". In contrast, P3 stated that he was unsure of the origin of the sensation when the controllers vibrate, and



(a) Mean Likert scores

(b) The participants' favorite variants

Figure 2: Mean Likert scores and favorite variants. (a) The figure illustrates the mean Likert scores (5 is best) given by participants for each variant of the feedback prototype, indicating the overall level of satisfaction with each variant. (b) The number of participants who preferred each variant.

P4 reported that the vibration felt unusual and she would not be able to focus on it. Further, P6 said, "That was way too strong [the vibration]. If this is supposed to be a subtle hint, it is too strong".

Improve Quality of Conversation. Participants generally found it helpful to receive a cue regarding eye contact (8). Even so, some participants found the cue more useful in certain situations. For example, P2 said it is helpful for him if the conversation partner is further away. Further, P9 reported that he typically hears from which direction he is being addressed. But, with his tunnel vision, and when several people in a group are talking to each other, it would be helpful for him to have cues. However, P8 mentioned, "I prefer to have an authentic conversation rather than a perfectly rehearsed one with different cues, but I recognize that in certain situations, such as a job interview, having a cue would be beneficial".

Evaluation of the Prototype. The participants voted on a 5-point Likert item (Fig. 2a) for the five different variants of the prototype. The results showed that the Visual Ray (*mean* = 4.04, *SD* = 1.23) received the highest score among all the variants. The Auditory Earcon (*mean* = 4, *SD* = 0.89), Tactile Cue (*mean* = 3.5, *SD* = 1.36), Auditory Icon (*mean* = 3.27, *SD* = 0.79), and Visual Flash (*mean* = 2.36, *SD* = 0.81) received lower scores. In addition, participants should decide on a variant they prefer (Fig. 2b). Here, Visual Ray (7) was preferred over Auditory Earcon (2) and Tactile Cue (2), Auditory Icon (0), and Visual Flash (0).

5 DISCUSSION

The aim of this exploratory study was to investigate how people with visual impairments perceive gaze cues from their counterparts in a conversation in VR and what eye contact generally means to them. The study presented assistive gaze cues via different sensory modalities, including visual, auditory, and tactile. Overall, our results showed that eye contact is important for our participants in a conversation and that they prefer cues that indicate where the speaker is located. Further, our findings indicated that in specific scenarios, participants felt uncomfortable when they could not perceive eye contact, highlighting the potential need for assistive gaze cues.

Participants rated the Visual Ray as the best, reflected in its high mean Likert scores and favored variant. The high contrast was positively perceived and helped those with tunnel vision orient themselves in conversations. However, it can become overwhelming in group conversations and obscure too much of the field of view for some participants. The Auditory Earcon generally received positive ratings from participants, but some had prior associations with it. Perception varied, with some finding it too quiet and others finding it just right. The effectiveness of the Auditory Icon was not clear as it uses cartoon sounds and may not be appropriate for serious conversations. The main advantage of the Tactile Cue is that it does not interfere with the visual and auditory channels during a conversation. Since the tactile channel normally does not process any input during a conversation, displaying cues via this channel can be advantageous. However, the Tactile Cue did not provide any information regarding which direction the gaze was coming from.

Previous research has already demonstrated the advantages of enabling individuals with visual impairments to perceive gaze [16, 17, 19]. For example, Qiu et al. [19] provided gaze via a wristband that vibrated when the visually impaired person was looked at by a conversation partner and Morrison et al. [16, 17] used spatialized audio to read aloud the name of the individual who was looking at the person with visual impairment. However, the authors did not examine the possibility of using different representations via sensory modalities or combinations of gaze cues to convey distinct gaze functions. The fact that participants find a gaze cue helpful and mention specific use cases shows how they could benefit from it. There are certain situations like a job interview (even if it is not conducted via VR), a group discussion, or when the conversation partner is further away, during which a cue may be relevant for people with visual impairments. The presented gaze cues in this exploratory study with different design options present a potentially versatile means to convey distinct gaze functions, thereby allowing for a more adaptable customization of gaze cues to suit varying situational demands. In summary, there is potential that properly designed gaze cues can enhance the quality of conversations in social virtual realities. Although previous research has explored the effectiveness of specific gaze cues such as tactile feedback and spatialized audio, there remains a gap in our understanding of how different types of gaze cues or combinations thereof may contribute to a more nuanced and comprehensive understanding of gaze cues for people with visual impairments in social VR. Additionally, our initial findings are not exclusively relevant to social VR and may have broader implications. For example, augmented reality glasses have been used to interpret facial expressions of the conversation partner and enhance the expression in real-time for people with visual impairments [14]. Similar situations would also be feasible for gaze cues in the real world.

6 FUTURE WORK

In our future work, we plan to investigate further assistive gaze cues for people with visual impairments to map the various functions of the gaze. This will primarily involve quantitative investigations during a conversation in VR. In addition, we will investigate how often, how long, or in combination with different sensory modalities these cues need to be presented to substitute eye contact functions. For instance, the continuous fading in of these cues could have negative or disturbing effects. Furthermore, it is important to keep in mind that individuals with visual impairments perceive the world differently and therefore have unique needs. Thus, a personalized approach is necessary.

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