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An Evaluation of a Wearable Assistive Device for Augmenting Social Interactions

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ABSTRACT Gaze behaviors contain rich information regarding a person's emotions and engagements. Reciprocal eye contact can invoke feelings of liking between two strangers. But blind people cannot perceive and establish the eye contact with sighted counterparts, causing their feelings of social isolation and low confidence in conversations. Thus, our research purpose is to let blind people perceive and react gaze behaviors in social interactions. A Social Glasses system has been implemented iteratively to deliver the multisensory feedback channels of the ''eye contact'', integrating both visual and tactile feedback. Specifically, the system consists of a Social Glasses device and a tactile wristband, which are worn by a blind person. The Social Glasses simulates the natural gaze for the blind person, aiming at establishing the ''eye contact'' between blind and sighted people. The tactile wristband enables the blind person to perceive the corresponding tactile feedback when an ''eye contact'' happens. To test the system, we conducted a user experiment with 40 participants, including 10 blind-sighted pairs ($N = 20$) and 10 blindfolded-sighted pairs ($N = 20$), to see how it could help increase the communication quality between blind and sighted people, as well as to suggest implications for its design. Our main findings demonstrated that both the simulated gaze and the tactile feedback were significantly effective to enhance the communication quality in blind-sighted conversations. Overall, we contribute (1) empirical research findings on how a Social Glasses system enhances the communication quality in blind-sighted conversations; and (2) design principles to inform future assistive wearable device for augmenting social interactions.

INDEX TERMS Accessibility, artificial gaze, assistive technology, communication quality, eye tracking, face-to-face communication, gaze contact, visual impairments.

I. INTRODUCTION

Blind people have benefited from other modalities already, such as hearing and touch. An example is regarding sensory compensation of blind people. Due to a loss of vision, some blind people are very sensitive for their hearing and touch modalities. But, accessing to nonverbal cues (e.g., gaze and eye contact) in social interactions is still vital to blind people. An old English proverb says: ''The eyes are the window to the soul''. Through gaze behaviors, some observers could gain a wealth of information such as a person's emotions, mental states [1] and attention [2], [3]. Gaze behaviors (e.g., eye contact) are visual cues, which blind people cannot perceive and respond to in social interactions; this shortcoming can explain their feelings of social isolation and low confidence in blind-sighted communication [4].

Abraham Maslow's hierarchy [5] suggested that, once the basic needs of a person are satisfied, he or she can strive to satisfy the need for love and belonging in social interactions. Assistive technology usually focuses on functionality and usability, yet technology use cannot happen in a social vacuum [6]. It is also important to support the social needs of blind people. Various socially assistive technologies for blind people have been developed, such as wearable devices to convey facial expressions [7], head nodding [8], and the social distance of sighted counterparts [9]. Most socially assistive systems use tactile feedback instead of auditory feedback. Auditory feedback is not well suited for social interactions

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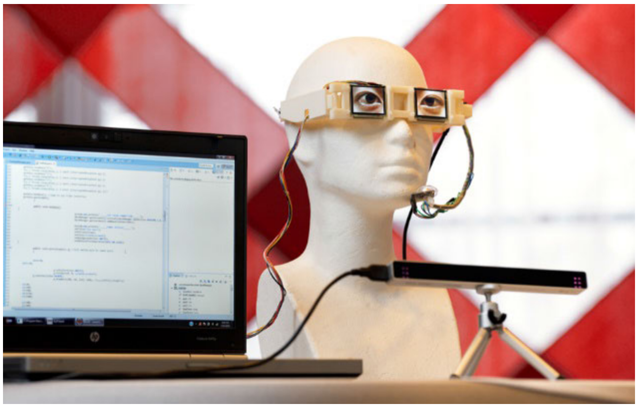

FIGURE 1. A dummy wore a glasses device with the interactive gaze (©Bart van Overbeeke, Eindhoven).

due to its interferences, especially in a conversation scenario. Tactile feedback is tacit, efficient to decrease hearing burden in conversations.

Qiu *et al.* [10], [11] asked opinions of 20 blind participants about a conceptual design of the glasses device. It aims to support blind people to perceive and react to gaze in social interactions. The participants expressed their great interest towards the concept of Social Glasses. This device could enable them to perceive gaze from sighted counterparts, to make them feel more confident and engaged in blind-sighted conversations. Gaze reaction is also important, since they want to be treated as normal and need proper support. Next, Qiu *et al.* [12] demonstrated the positive impact of the simulated gaze in a human-dummy monologue scenario (Fig. 1). Qiu *et al.* [13] improved the interactive gaze model, and tested four gaze conditions (i.e., No Gaze, Constant Gaze, Random Gaze, and Interactive Gaze) in blind-sighted conversations. The results showed that Interactive Gaze was more effective than other three gaze conditions. But, the system cannot provide any feedback to blind people. It focuses on satisfying the needs of sighted people to establish the ''eye contact''.

Here, we integrate both visual and tactile feedback in gaze simulation. A tactile wristband is added to the Social Glasses system [13], enabling blind people to perceive the ''eye contact''. The system delivers multisensory experience of the ''eye contact''. Finally, we recruit 40 participants to test the system in dyadic blind-sighted conversations. The setup and the results of the experiment are presented in Chapter 6 of the first author's PhD dissertation [14]. This paper presents the related research more coherently and comprehensively based on this experiment.

II. RELATED WORK

A. ISSUES RELATED TO BLIND PEOPLE IN SOCIAL INTERACTIONS

Social signals convey one's attitudes and emotions towards social situation through a multiplicity of nonverbal cues (e.g., gaze, facial expressions) [15]. McNeill [16] suggested that nonverbal cues are integral to a conversation, and ignoring them means ignoring part of the conversation. Krishna *et al.* [17] conducted two focus groups to investigate blind people's difficulties of perceiving nonverbal cues. Engaging with their sighted counterparts was identified as an important problem. For instance, if a sighted person wanted to ask a question in a group, she could use gaze direction and eye contact to indicate that person. However, because of lacking visual cues, a blind person was not able to realize that whether the question was directed towards him. Qiu *et al.* [11] interviewed 20 blind and low-vision participants regarding social signal perception in face-to-face communication. As reported, they could not see and establish the eye contact with the sighted conversation partners. Due to a lack of direct eye contact, they felt difficult to engage in conversations and understand conversation partners' feelings. Griffin's Uncertainty Reduction theory [18] suggested that without visual cues, blind people often feel uncertain about the sighted counterparts' attitudes, causing their low-confidence and feelings of social isolation [4].

Some researchers developed social skills training to improve the quality of face-to-face communication for blind people. Such effort has been well performed based on social psychology, which documented the significance of gaze behaviors (e.g., eye contact) in communication [19], [20]. The treatment techniques such as direct instructions are often used to improve the performance of blind people on nonverbal responses [21], [22]. For instance, a blind person was asked to turn his head and simply ''look'' in the direction of a sighted person who was talking to him. However, such responses from blind people still look stereotyped and unnatural to sighted people. Gaze and eye contact link many psychological processes, regarded as a remarkably useful source of information during face-to-face communication [23]. Thus, it is of great importance to simulate proper gaze for blind people in social interactions.

This section highlights the need for studies to increase the overall knowledgebase concerning the importance of blind people's gaze perception and reaction. This type of studies should lead technological innovation towards the development of innovative and usable assistive systems.

B. SOCIAL SIGNAL PERCEPTION AND TECHNOLOGY

Many assistive technologies for blind people has traditionally focused on mobility, navigation, and object recognition; but more recently on social interaction as well [24], [25]. An increasing number of studies explored to assist blind people in social situations based on smart technologies, such as identify faces and facial expressions of the sighted counterparts [7]–[28]. A facial recognition system can help blind people to identify colleagues in group meetings [27]. Blind people hear that person's name through a wireless earpiece when a colleague's face is identified. Without vision, the hearing modality is most useful for blind people to perceive surroundings. Most assistive systems often make use of their hearing modality (e.g., voice navigation).

However, the auditory feedback sometimes obstructs conversations and other auditory signals in social situations. Instead of delivering information through sense of hearing, McDaniel *et al.* [29] presented the Haptic Face Display (HFD), aiming at efficiently and discreetly conveying nonverbal social cues. HFD allows blind people to feel the facial movements of the interaction partners. In the HFD system, 48 vibration motors are mounted on the back of a chair to best map the facial movements and the corresponding vibration cues. Buimer *et al.* [26] introduced a sensory substitution device (SSD) to support blind people to determine facial expressions of their interaction partners. The SSD classifies six universal facial expressions [30] into emotions, conveying vibrotactile stimuli by a belt. They tested the system and demonstrated that vibrotactile cues were well suited to convey facial expressions to blind people in real-time. Meza-de-Luna *et al.* [8] introduced a Social-Aware Assistant (SAA) to help blind people perceive a head nodding of the conversation partner through the tactile feedback.

Among various social signals, gaze plays an important role. Only a few studies explored how to deliver gaze information to blind people. For instance, Sarfraz *et al.* [31] developed a vibrotactile belt to let blind people perceive gaze directions in social interactions. But this device cannot send the gaze reaction to the sighted counterparts. Blind people are only treated as the receivers of gaze information. In this paper, we aim to develop an assistive system that not only allows blind people to perceive the gaze, but also delivers the gaze reaction to the sighted counterparts.

C. SOCIAL GAZE BEHAVIORS

Social gaze behaviors have been widely explored in the research field of HAI (Human-Agent Interaction). Gaze behaviors of a virtual agent elicit natural responses in humans [32]. In human-agent conversations, deploying gaze behaviors of the agent strategically can achieve positive outcomes [33]. For instance, a virtual agent showing gaze attention and positivity to a sighted person can greatly improve their feelings of rapport [34].

Many psychologists have studied gaze behaviors linking with conversation turns, since conversation turns are treated as a valuable means to attend in social life [35]. Argyle and Roger [36] measured gaze amount with dyadic (two-person) conversations in lab-based user experiments. They observed that people looked more at the conversation partner while listening than speaking. Informed by findings in psychology, Heylen *et al.* [37] studied the effects of different gaze behaviors of a cartoon-like talking face (Karin) on the quality of human-agent dialogues. Their findings showed that the simulated gaze behaviors based on a turn-taking model positively influenced the dialogue quality. Besides the turn-taking strategy, reactive systems are also applied to design social gaze. In such systems, a user's gaze behaviors trigger a momentary response from a virtual agent, which in turn influences the user and results in a feedback loop [32]. For instance, Bee *et al.* [38] implemented a reactive gaze model for the virtual agent to improve the user experiences in an interactive storytelling scenario. Based on the eye-tracking technology, a virtual agent can create "eye contact" by shifting its gaze in reaction to a sighted person's gaze. Experimental results demonstrated that the interactive gaze positively improved user perceptions of social presence and rapport. In summary, these research findings are helpful for us to design social gaze for blind people.

III. SOCIAL GLASSES

In earlier studies, we implemented the Interactive Gaze of the Social Glasses [12], [13], [39]. Here, we integrate the Interactive Gaze with the tactile feedback and make the working system available for the user experiments in a dyadic-conversation scenario.

A. DESIGN

In our prior work, an interactive gaze model was implemented based on the eye-contact mechanism and the turn-taking strategy. The details of that gaze model has been illustrated in [18, Fig. 1]. In this paper, the modified gaze model adds the tactile feedback. The recent system includes both Social Glasses and a tactile wristband. Whenever a sighted person looks towards the Social Glasses, it reacts a "look at" eye gesture, and holds it for one second to establish the "eye contact." Meanwhile, the blind person can perceive the corresponding tactile feedback for one second from his wristband.

To avoid obstructing conversations and other auditory signals, we use the tactile feedback to efficiently and discreetly convey the "eye contact." We choose the wrist of blind people to perceive the tactile feedback, because it is one of the most preferred positions for perceiving the vibration [40]. Since the tactile perception of the dominant hand is more sensitive than the other hand [41], we let blind people wear the tactile wristband on the dominant hands.

B. ITERATIVE IMPLEMENTATION

In the earlier system [13], Interactive Gaze was driven by both gaze signals and audio signals. An Eye Tribe tracker[1] was used to detect gaze signals from sighted people for implementing the eye-contact mechanism, while a sound detector was used for the turn-taking strategy. Here, the Social Glasses was developed by adding a vibration motor to the earlier system [13]. The vibration motor was fixed inside a soft wristband to provide the tactile feedback to a blind person. Whenever a sighted person is looking at the Social Glasses, the sensor module will track that person's gaze and send the gaze data to the Arduino board. The Arduino board activates the vibration motor to send the corresponding tactile feedback for one second to a blind person.

The system consists of an Eye Tribe Tracker, a laptop, a vibration motor, an Arduino microcontroller, two 1.7″ Intelligent OLED modules with an embedded graphics processor, a sound detector, and a physical glasses-shaped prototype.

[1] http://theeyetribe.com/theeyetribe.com/about/index.html

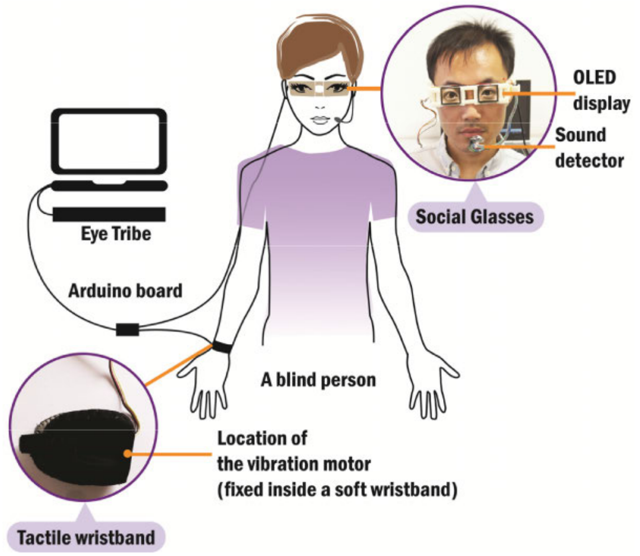

FIGURE 2. The system overview (a test subject wore the social glasses, picture with consent).

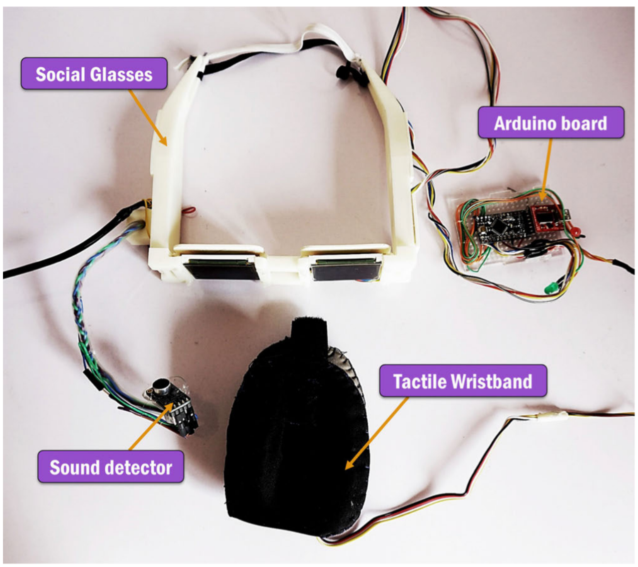

FIGURE 3. Components of the prototypes of the social glasses with the tactile wristband.

The digital model of the glasses-shaped shape prototype was built by the software Rhinoceros for 3D printing. Fig. 2 and Fig. 3 show the system overview and the prototype components.

IV. EXPERIMENT

In the prior work [13], we tested the impact of the interactive gaze displayed on the Social Glasses under four gaze conditions. Sighted participants perceived Interactive Gaze was more effective than No Gaze, Constant Gaze, and Random Gaze to improve the communication quality. However, blind participants could not perceive any direct feedback from the system. The previous system focused on improving the user experience of sighted conversation partners. Here, we have an exploration to deliver the multisensory feedback channels of the "eye contact", integrating both visual and tactile feedback. We aim to enhance the communication quality of both blind and sighted people in face-to-face communication.

Due to a limited number of truly blind participants and challenges to find them, we involved blindfolded participants, who simulated the disability being studied. This approach has been widely used in HCI studies [42]–[44]. Here, we recruited sighted, blind and blindfolded participants for the user experiment. Blindfolded participants wore the blindfolds during the entire experiment to simulate the blindness. All participants were divided into two groups: the blind-sighted group and the blindfolded-sighted group.

A. HYPOTHESES

We formulated the hypotheses as outlined below regarding how the tactile feedback (active vs. non-active) and the interactive gaze (active vs. non-active) would affect the communication quality.

(**H1**) All participants will perceive greater communication quality when the tactile feedback is active than it is not.

(**H2**) All participants will perceive greater communication quality when the interactive gaze is active than it is not.

We also wanted to know how the tactile feedback and the interactive gaze influenced the communication quality in the blind-sighted group. Thus, we formulated the following hypotheses:

(**H3**) The participants in the blind-sighted group will perceive greater communication quality when the tactile feedback is active than it is not.

(**H4**) The participants in the blind-sighted group will perceive greater communication quality when the interactive gaze is active than it is not.

B. EXPERIMENTAL DESIGN

In response to (H1) and (H2), we presented a $2 \times 2 \times 2 \times 2$ mixed factorial experimental design, using the Tactile Feedback (active, non-active) and the Interactive Gaze (active, non-active) as the within-subjects factors, the conversation groups (blind-sighted, blindfolded-sighted) and the participant roles (non-sighted participants, sighted participants) as the between-subjects factors. Non-sighted participants include both blind and blindfolded participants.

In response to (H3) and (H4), we presented a $2 \times 2 \times 2$ mixed factorial experimental design, using the Tactile Feedback (active, non-active) and the Interactive Gaze (active, non-active) as the within-subjects factors, and the participant roles (blind participants, sighted participants) as the between-subjects factors.

Forty participants were recruited and made up 20 pairs, including 10 blind-sighted pairs and 10 blindfolded-sighted pairs. Two types of pairs followed the similar procedure in the user experiment. In the blind-sighted pair, a blind participant wore both the Social Glasses and the tactile wristband. She discussed a given daily topic with a sighted participant. Two participants had four conversations with each other, and each

TABLE 1. Four test conditions of the social glasses system.

Test Conditions	Tactile (T) Feedback (yes=Y/no=N)	Interactive (I) Gaze (yes=Y/no=N)
TNIN	no	no
TNIY	no	yes
TYIN	yes	no
TYIY	yes	yes

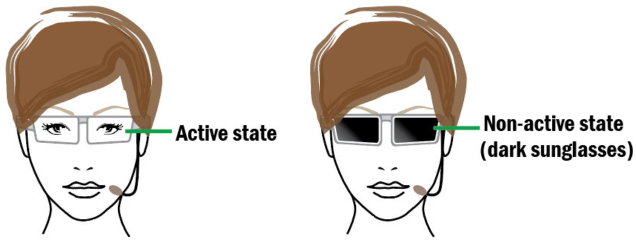

FIGURE 4. Two states of the interactive gaze displayed on the social glasses.

conversation took around 10 minutes. Four conversations took place under four test conditions with a counterbalanced order to avoid carry-over effects. Four test conditions are shown in Table 1. TNIN refers to the condition that both Tactile Feedback and Interactive Gaze are not active. TNIY refers to the condition that Tactile Feedback is not active and Interactive Gaze is active. TYIN refers to the condition that Tactile Feedback is active and Interactive Gaze is not active. TYIY refers to the condition that both Tactile Feedback and Interactive Gaze are active.

In the experimental design, we identified four independent variables:

The *first independent variable* is the state of the Tactile Feedback. This variable is treated as a within-subject factor. It has two conditions: (1) the active state, and (2) the non-active state.

The *second independent variable* is the state of the Interactive Gaze. This variable is treated as a within-subject factor. It has two conditions: (1) the active state, and (2) the non-active state (Fig. 4).

We documented the information of the participants' dominant hands. They were all right-handed, due to the reason that traditional values and practical considerations reduced the prevalence of left-handedness in China [45]. Table 2 illustrates the vision conditions of the blind participants.

The active state displays Interactive Gaze, while the non-active state does not provide any gaze feedback. It looks similar as the dark sunglasses.

The *third independent variable* is the type of the conversation groups. This variable is treated as a between-subject factor. It has four conditions: (1) the blind-sighted group, and (2) the blindfolded-sighted group.

The *fourth independent variable* is the role of the participants. This variable is treated as a between-subject factor. It has two conditions: (1) the non-sighted participants, and (2) the sighted participants.

TABLE 2. Vision conditions of the blind participant (N = 10; sorted by vision impairment from low to high).

Gender	Age in years	Vision Conditions (WHO standard) [a]	Congenital Blindness	Light Perception
male	16	Moderate visual impairment	no	yes
male	18	Moderate visual impairment	yes	yes
male	17	Moderate visual impairment	yes	yes
female	16	Moderate visual impairment	no	yes
female	15	Blindness 3	no	yes
male	16	Blindness 4	no	yes
male	15	Blindness 5	no	no
male	17	Blindness 5	yes	no
female	16	Blindness 5	yes	no
female	16	Blindness 5	yes	no

C. PARTICIPANTS

In this study, we recruited 40 participants including 10 blind participants. We conducted the user experiments in two locations in China: blind-sighted conversations in Yangzhou Special Education School (YZSES), and blindfolded-sighted conversations in Shanghai Jiao Tong University (SJTU) in Shanghai.

The selection of blind participants is based on three criteria: (1) they are registered blind in China Disabled Persons' Federation [46]; (2) blindness is the only significant handicap (e.g., no mix with autism or other illness); (3) they are not children, since studying blind children may require other additional effort (e.g., specific support from their parents, or choosing other suitable methodology in HCI). In practice, it is very difficult to find sufficient number of qualified blind participants and let them attend controlled user experiments in a lab. So, we directly contacted teachers from YZSES to select blind participants. For the sighted participants, they are students from university or college without any special selection criterion. They only have to guarantee the sufficient flexible time to attend the experiment.

In 10 blind-sighted pairs (M_{age} = 16.55, SD =.83, N = 8 females vs. 12 males), most blind participants were selected from the 8th grade from YZSES, with the ages ranging from 15-18. We recruited the sighted participants from Jiangsu College of Tourism (JCT) with the help of the teachers. Their ages ranged from 16-18. We matched two participants in one pair with the similar age and the same gender, so they could easily generate discussions, and avoid any possible heterosexual effect in the conversations.

In 10 blindfolded-sighted pairs (M_{age} = 23.45, SD = 2.67, N = 12 females vs. 8 males), both blindfolded and sighted participants were university students from SJTU. We posted the recruitment information on the university website (tongqu.me) to find out qualified participants. In one pair, two participants are also matched with the similar age and the same gender. Compensation for each participant was 100 CNY for approximately three hours.

We documented the information of the participants' dominant hands. They were all right-handed, due to the reason that traditional values and practical considerations reduced the prevalence of left-handedness in China [45]. In this study, we want to know whether design intervention has a positive impact on blind population with different level of visual impairments, ranging from moderate visual impairment to totally blindness. We do not use the level of visual impairment as a factor (e.g., moderate visual impairment or totally blindness). If we separate blind participants into sub-groups based on their different level of visual impairment, the number of blind participants in each sub-group is quite small. It is not able to do a convincing quantitative analysis and apply inferential statistics. In addition, blind participants wore the Social Glasses in user experiments. The glasses device covers their eyes, and it is not transparent. Visual acuity of each blind participant is almost at the same level. Thus, we do not need accurate visual acuity, and do not consider visual acuity of blind participants as a significant factor that can affect the experimental results.

D. SETUP AND PROCEDURE

The participants were divided into pairs to take dyadic conversations. A non-sighted participant wore the Social Glasses and the tactile wristband. She sat in front of a sighted participant. The distance between two participants was around 1.8m, indicating a comfortable social distance for people sitting in chairs or gathering in a room [47]. The eye tracker was installed about 0.5m away from the sighted participant. To ensure the stability of gaze tracking, a comfortable pillow was used to support the neck of the sighted participant. The observation camera captured the whole scene. Fig. 5 shows the experimental setup.

The study was conducted according to the Declaration of Helsinki. All the participants were informed about the study and gave their consent to participate. In the experiment, the participants signed consent forms and completed pre-experimental questionnaires. In the blind-sighted pair, a volunteer who did not belong to the research team was invited to observe the consent process. The volunteer orally presented the consent form to the blind participant. The participant was offered with enough time to ask questions about the content of the consent for the understanding. With clear understanding, she gave the consent for participating in the research, and orally presented her name and the date. The volunteer also orally presented his name and the date, then signed and dated the form for the blind participant. The whole consent procedure was audio recorded as the part of the documentation of the consent forms.

Next, the participants filled in their demographic information in the pre-experimental questionnaire. Then non-sighted participants wore the Social Glasses and the tactile wristband.

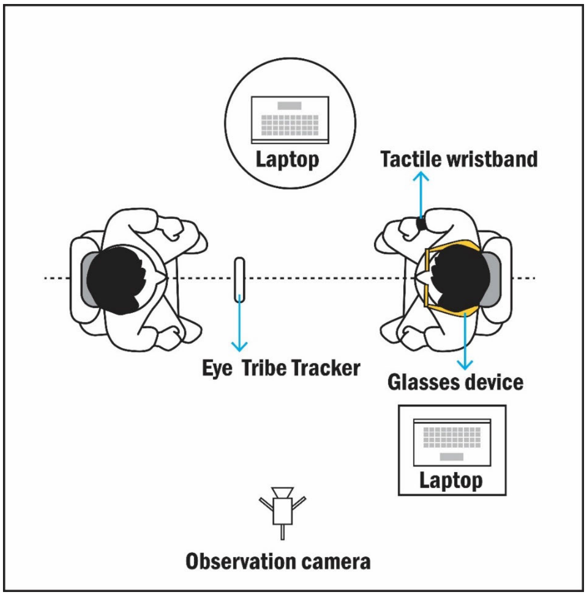

FIGURE 5. Overhead view of the experimental setup: the eye tribe tracker detected the gaze from a sighted participant, and a non-sighted participant wore the glasses device and the tactile wristband.

In the blindfolded-sighted pair, one participant was randomly selected to wear the blindfold. We ensured the participant's comfort to the blindness and this participant needed to wear the blindfold during the entire experiment, including answering the questionnaires.

Fourteen daily topics were randomly selected from the IELTS oral exam [48]. The topics should be easy for the participants to start a discussion such as "Describe an object you particularly like." The participants in the same pair prepared the given topic for three minutes. After completing the calibration of the eye tracker for the sighted participant, two participants started to have a conversation, which lasted for 10 minutes. After that, the participants completed the post-experimental questionnaires. The researcher orally presented the contents of the questionnaires to the non-sighted participants, and completed the questionnaires based on their oral answers. Four rounds of 10-minutes conversations were taken place under four test conditions (Table 1) of the Social Glasses system with a counterbalanced order to avoid carry-over effects. Finally, we interviewed them to collect their comments about the system. The conversations were videotaped, and the interviews were audiotaped. Because oral presentations and answers to the post-experimental questionnaires for four times is time consuming, the overall experiment of the blind-sighted pairs lasted about 3 hours and the blindfolded-sighted pairs lasted about 2.5 hours. Table 3 presents the experimental procedure of two conversation groups.

E. MEASUREMENTS

1) SUBJECTIVE QUESTIONNAIRES

In social science, the quality of face-to-face communication is closely related to social presence, which measures

TABLE 3. The experimental procedure of two conversation groups. (BS: blind-sighted pairs; BFS: blindfolded-sighted pairs.)

	Experimental Procedure	Duration
1	Read and sign consent forms. A volunteer helps blind participants in the consent process. Fill in pre-experimental questionnaire.	BS & BFS: 10 min
2	Blindfolded participants experience being blindfolded.	BFS: 10 min
3	Test I ; Complete the post-experimental questionnaire. The researcher orally presents the questionnaire to the non-sighted participants.	BS: 40 min BFS: 30 min
4	Test II ; Complete the post-experimental questionnaire. The researcher orally presents the questionnaire to the non-sighted participants.	BS: 40 min BFS: 30 min
5	Test III ; Complete the post-experimental questionnaire. The researcher orally presents the questionnaire to the non-sighted participants.	BS: 40 min BFS: 30 min
6	Test IV ; Complete the post-experimental questionnaire. The researcher orally presents the questionnaire to the non-sighted participants.	BS: 40 min BFS: 30 min
7	The interview for the open questions	BS & BFS: 10 min

the perception of the other with whom one is interacting [49]. Thus, we used two subjective questionnaires to measure the communication quality between blind and sighted people: the "Networked Minds Social Presence Inventory" (NMSPI) [50] and the "Inclusion of Other in the Self" (IOS) Scale [51].

NMSPI measures "social presence", which means the "sense of being with another" [49]. "Another" refers to either a human or an artificial agent [49]. NMSPI includes 36 items with a seven-point response scale ranging from one (strongly disagree) to seven (strongly agree). It is composed of six sub-dimensions: (1) *co-presence*, (2) *attentional allocation*, (3) *perceived message understanding*, (4) *perceived affective understanding*, (5) *perceived emotional interdependence*, and (6) *perceived behavioral interdependence*.

(1) *Co-presence* refers to the level of awareness of the partner, such as the item "I noticed my partner."

(2) *Attentional allocation* means the amount of attention that a person provides to, and receives from the partner (e.g., "I was easily distracted from my partner when other things were going on").

(3) *Perceived message understanding* illustrates the ability that a person could understand the message from the partner (e.g., "My partner found it easy to understand me").

(4) *Perceived affective understanding* refers to a person's ability to understand a partner's emotion and attitudes (e.g., "I could describe my partner's feelings accurately").

(5) *Perceived emotional interdependence* illustrates the extent that a person's emotional state affects, and is affected by the partner (e.g., "My partner was sometimes influenced by my moods").

(6) *Perceived behavioral interdependence* refers to the extent that a person's behavior affects and is affected by the partner (e.g., "My behavior was often in direct response to my partner's behavior").

For each statement in NMSPI, the participant will be asked how true it is for him or her, using the following scale: 1. Strongly Disagree, 2. Disagree, 3. Somewhat Disagree, 4. Neutral, 5. Somewhat Agree, 6. Agree, and 7. Strongly Agree. An example is shown as below:

I noticed my partner:

Strongly Disagree	Disagree	Disagree Somewhat	Neutral	Agree Somewhat	Agree	Strongly Agree
1	2	3	4	5	6	7

IOS scale measures the closeness. It includes seven increasingly overlapping circle pairs, indicating the distance of the relationship between themselves and their conversation partners. Because the non-sighted participants cannot see the circle pairs, we use the percentage of the overlapped areas of two circles (i.e., 0%, 15%, 30%, 45%, 60%, 75%, and 90%) to match seven options. In the experiment, the researcher orally presented each option to the non-sighted participants.

2) VIDEO ANALYSIS

In the video analysis, we want to analyze who initiates the conversation. It is an important dimension in face-to-face communication, reflecting whether a participant has an active attitude during interactions [52]. We use the scoring of "1" or "0" in the video analysis. "1" stands for the participant to initiate a conversation and "0" stands for not initiating.

3) OPEN QUESTIONS

We collect qualitative feedback with open questions and interviews. After four tests, we have a short interview to ask the participants some open questions as below:

(1) Do you have an interest in this system? If yes, why are you interested in the system?

(2) Which aspects make you like or dislike this system?

(3) What do you think the function of the system in the conversation?

(4) Do you have any other suggestions for improving this system?

V. RESULTS

The quantitative results included three parts: (1) analysis of interventions in all participants, (2) analysis of interventions in the blind-sighted group, and (3) video analysis. The presented results are based on the work already discussed in [15].

A. QUANTITATIVE RESULTS

1) ANALYSIS OF INTERVENTIONS IN ALL PARTICIPANTS

Co-Presence: The predicted main effect of the Tactile Feedback was significant [$F(1, 36) = 4.293, p = .045, \eta_p^2 = .107$]. The contrast revealed that the participants felt significantly higher co-present when the Tactile Feedback was active (M = 5.41, SE =.11) than it was not (M = 5.14, SE =.13). In addition, the predicted main effect of the Interactive Gaze was significant [F(1, 36) = 63.730, p < .001, η_p^2 = .639]. The contrast revealed that the participants felt significantly higher co-present when the Interactive Gaze was active (M = 5.57, SE =.11) than it was not (M = 4.99, SE =.11).

A non-significant interaction effect was observed between the state of the Tactile Feedback and the participant roles [F(1, 36) = 3.070, p = .088], but a significant interaction effect was observed between the state of the Interactive Gaze and the participant roles [F(1, 36) = 47.351, p < .001, η_p^2 = .568]. It indicated that the non-sighted participants' co-presence was generally the same whether the Interactive Gaze was active or not, while the sighted participants felt significantly higher co-present when the Interactive Gaze was active than it was not.

Attention Allocation: Although the predicted main effect of the Tactile Feedback was not significant [F(1, 36) = 3.062, p = .089], the predicted main effect of the Interactive Gaze was significant [F(1, 36) = 21.441, p < .001, η_p^2 = .373]. The contrast revealed that the participants perceived significantly higher attention allocation when the Interactive Gaze was active (M = 5.13, SE =.15) than it was not (M = 4.61, SE =.13).

A non-significant interaction effect was observed between the state of the Tactile Feedback and the participant roles [F(1, 36) =.980, p = .329]. However, a significant interaction effect was observed between the state of the Interactive Gaze and the participant roles [F(1, 36) = 11.045, p = .002, η_p^2 = .235]. It indicated that the non-sighted participants' attention allocation was generally the same whether the Interactive Gaze was active or not, while the sighted participants perceived significantly higher attention allocation when the Interactive Gaze was active than it was not.

Perceived Message Understanding (PMU): Although the predicted main effect of the Tactile Feedback was not significant [F(1, 36) = 3.744, p = .061], the significant main effect of the Interactive Gaze was observed [F(1, 36) = 11.603, p = .002, η_p^2 = .244]. The contrast revealed that the participants perceived significantly higher PMU when the Interactive Gaze was active (M = 5.18, SE =.16) than it was not (M = 4.83, SE =.15).

A non-significant interaction effect was observed between the state of the Tactile Feedback and the participant roles [F(1, 36) =.399, p = .532], but there was a significant interaction effect between the state of the Interactive Gaze and the participant roles [F(1, 36) = 10.208, p = .003, η_p^2 = .221]. It indicated that the non-sighted participants' PMU was generally the same whether the Interactive Gaze was active or not. However, the sighted participants perceived significantly higher PMU when the Interactive Gaze was active than it was not.

Perceived Affective Understanding (PAU): The predicted main effect of the Tactile Feedback was significant [F(1, 36) = 11.208, p = .002, η_p^2 = 237]. The Contrast revealed that the participants perceived significantly higher PAU when the Tactile Feedback was active (M = 4.50, SE =.17) than it was not (M = 4.16, SE =.19). In addition, a significant main effect of the Interactive Gaze was observed [F(1, 36) = 10.592, p = .002, η_p^2 = .227]. The contrast revealed that the participants perceived significantly higher PAU when the Interactive Gaze was active (M = 4.50, SE =.18) than it was not (M = 4.17, SE =.18).

Although a non-significant interaction effect was observed between the state of the Tactile Feedback and the participant roles [F(1, 36) = 2.220, p = .145], the interaction effect between the state of the Interactive Gaze and the participant roles was significant [F(1, 36) = 9.883, p = .003, η_p^2 = .215]. It indicated that the non-sighted participants' PAU was generally the same whether the Interactive Gaze was active or not, while the sighted participants perceived significantly higher PAU when the Interactive Gaze was active than it was not.

Perceived Emotional Interdependence (PEI): Although the predicted main effect of the Tactile Feedback was not significant [F(1, 36) =.213, p = .647], a significant main effect of the Interactive Gaze was observed [F(1, 36) = 4.834, p = .034, η_p^2 = .118]. The contrasts revealed that the participants perceived significantly higher PEI when the Interactive Gaze was active (M = 4.38, SE =.19) than it was not (M = 4.21, SE =.18).

A non-significant interaction effect was observed between the state of the Tactile Feedback and the participant roles [F(1, 36) =.708, p = .406], but there was a significant interaction effect between the state of the Interactive Gaze and the participant roles [F(1, 36) = 22.124, p < .001, η_p^2 = .381]. It indicated that the non-sighted participants' PEI was generally the same whether the Interactive Gaze was active or not, while the sighted participants perceived significantly higher PEI when the Interactive Gaze was active than it was not.

Perceived Behavioral Interdependence (PBI): The predicted main effect of the Tactile Feedback was not significant [F(1, 36) = 3.881, p = .057], but the main effect of the Interactive Gaze was significant [F(1, 36) = 45.811, p < .001, η_p^2 = .560]. The contrast revealed that the participants perceived significantly higher PBI when the Interactive Gaze was active (M = 4.81, SE =.15) than it was not (M = 4.28, SE =.14).

A non-significant interaction effect was observed between the state of the Tactile Feedback and the participant roles [F(1, 36) =.735, p = .397]. However, the interaction effect between the state of the Interactive Gaze and the participant roles was significant [F(1, 36) = 25.575, p < .001, η_p^2 = .415]. It indicated that the non-sighted participants' PBI was generally the same whether the Interactive Gaze was active or not, while the sighted participants perceived significantly higher PBI when the Interactive Gaze was active than it was not.

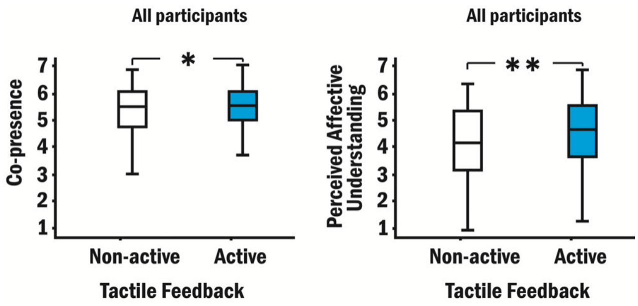

FIGURE 6. Boxplot of the main effect of the tactile feedback on the participants' co-presence (left figure) and PAU (right figure). Significant group difference; * $p < .05$, ** $p < .01$.

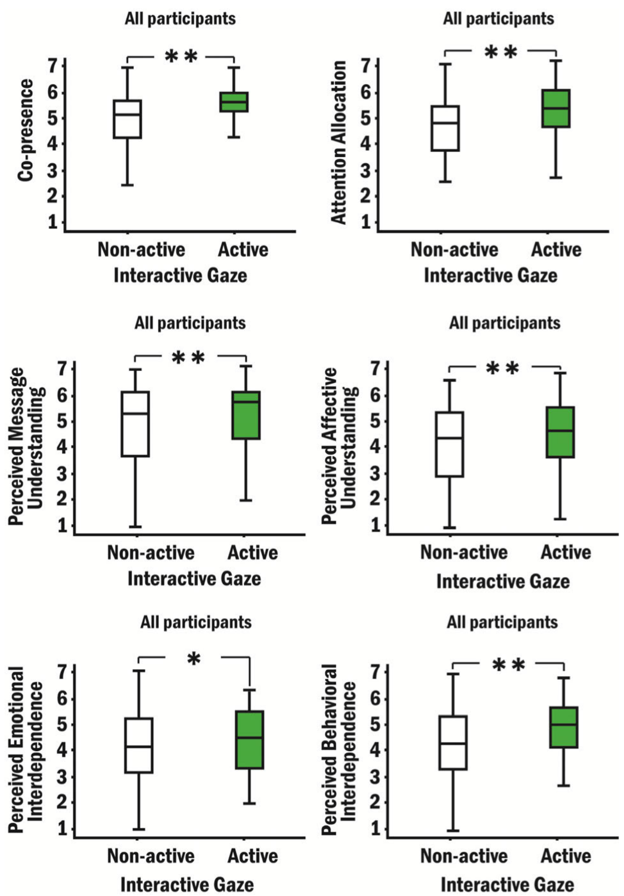

FIGURE 7. Boxplot of the main effect of the interactive gaze on the participants' co-presence, attention allocation, PMU, PAU, PEI and PBI. Significant group difference; * $p < .05$, ** $p < .01$.

Closeness: The predicted main effect of the Tactile Feedback was not significant [F(1, 36) =.005, p = .943]. There was also a non-significant main effect of the Interactive Gaze [F(1, 36) =.061, p = .807].

In addition, a non-significant interaction effect was observed between the state of the Tactile Feedback and the participant roles [F(1, 36) =.619, p = .437]. A non-significant interaction effect was also observed between the state of the Interactive Gaze and the participant roles [F(1, 36) =.007, p = .935].

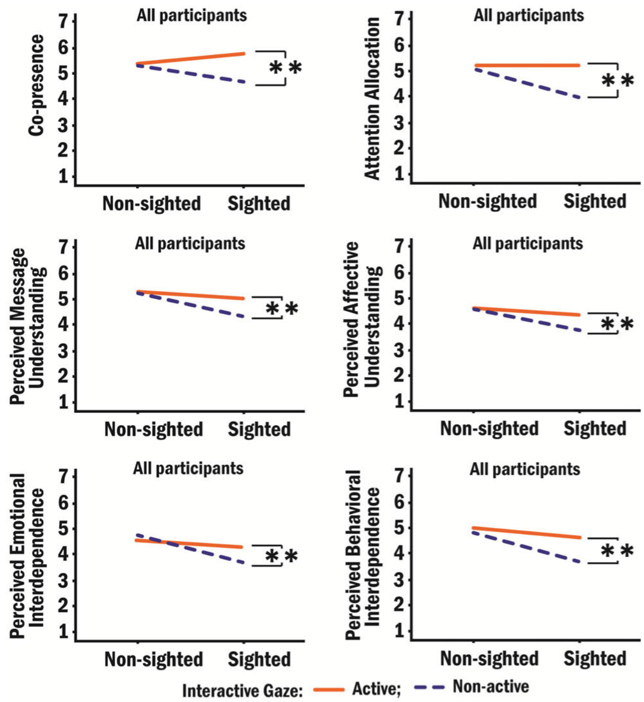

FIGURE 8. Interaction effects between the participant roles and the interactive gaze on the participants' co-presence, attention allocation, PMU, PAU, PEI and PBI. Significant group difference; * $p < .05$, ** $p < .01$.

Summary: The participants perceived significantly higher co-presence and PAU when the Tactile Feedback was active than it was not (Fig. 6). However, the interaction effect between the Tactile Feedback and the participant roles was not significant. Also, the Interactive Gaze positively affected the participants' co-presence, attention allocation, PMU, PAU, PEI and PBI in conversations (Fig. 7). A significant interaction effect was also observed between the Interactive Gaze and the participant roles. It revealed that the sighted participants perceived significantly higher co-presence, attention allocation, PMU, PAU, PEI and PBI when the Interactive Gaze was active than it was not (Fig. 8).

2) ANALYSIS OF INTERVENTIONS IN THE BLIND-SIGHTED GROUP

To further investigate the effect of the Tactile Feedback and the Interactive Gaze in the blind-sighted conversations, we analyzed the experimental data only from the blind-sighted group. A 2 × 2 × 2 mixed ANOVA was conducted, using the Tactile Feedback (active, non-active) and the Interactive Gaze (active, non-active) as the within-subjects factors, and participant roles (blind participants, sighted participants) as the between-subjects factor.

Co-Presence: A non-significant main effect of the Tactile Feedback was observed [F(1, 18) = 1.854, p = .190]. Although not significant, the participants felt higher co-present when the Tactile Feedback was active (M = 5.52, SE =.16) than it was not (M = 5.21, SE =.21). The predicted main effect of the Interactive Gaze was significant [F(1, 18) = 4.960, p = .039,

$\eta_p^2 = .216$]. The contrast revealed that the participants in the blind-sighted group felt significantly higher co-present when the Interactive Gaze was active (M = 5.456, SE =.16) than it was not (M = 5.26, SE =.15).

A non-significant interaction effect was observed between the state of the Tactile Feedback and the participant roles, F(1, 18) = 1.308, p = .268. A non-significant interaction effect was also observed between the state of the Interactive Gaze and the participant roles, F(1, 18) = 1.084, p = .312.

*Attention Allocation:*The predicted main effect of the Tactile Feedback was not significant [F(1, 18) = 3.090, p = .096]. Although not significant, the participants perceived higher attention allocation when the Tactile Feedback was active (M = 5.08, SE =.23) than it was non-active (M = 4.78, SE =.26). The predicted main effect of the Interactive Gaze was also not significant [F(1, 18) = 2.673, p = .119].

A non-significant interaction effect was observed between the state of the Tactile Feedback and the participant roles [F(1, 18) =.685, p = .419]. A non-significant interaction effect was also observed between the state of the Interactive Gaze and the participant roles [F(1, 18) =.470, p = .502].

Perceived Message Understanding (PMU): The predicted main effect of the Tactile Feedback was not significant [F(1, 18) =.393, p = .539]. Although not significant, the participants perceived higher attention allocation when the Tactile Feedback was active (M = 5.01, SE =.25) than it was not (M = 4.92, SE =.25). The predicted main effect of the Interactive Gaze was also not significant [F(1, 18) = 2.561, p = .127].

A non-significant interaction effect was observed between the state of the Tactile Feedback and the participant roles [F(1, 18) =.464, p = .504]. However, a significant interaction effect was observed between the state of the Interactive Gaze and the participant roles [F(1, 18) = 5.070, p = .037, η_p^2 = .220]. It indicated that the blind and blindfolded participants' PMU was generally the same whether the Interactive Gaze was active or not, while the sighted participants perceived significantly higher PMU when the Interactive Gaze was active than it was not.

Perceived Affective Understanding (PAU): The predicted main effect of the Tactile Feedback was not significant [F(1, 18) = 2.895, p = .106]. Although not significant, the participants perceived higher PAU when the Tactile Feedback was active (M = 4.49, SE =.26) than it was not (M = 4.21, SE =.30). The main effect of the Interactive Gaze was also not significant [F(1, 18) = 1.398, p = .252].

A non-significant interaction effect was observed between the state of the Tactile Feedback and the participant roles [F(1, 18) = 3.969, p = .062]. There was also a non-significant interaction effect between the state of the Interactive Gaze and the participant roles [F(1, 18) =.314, p = .582].

Perceived Emotional Interdependence (PEI): The predicted main effect of the Tactile Feedback was not significant [F(1, 18) = 2.080, p = .166]. Although not significant, the participants perceived higher PEI when the Tactile Feedback was active (M = 4.22, SE =.29) than it was not (M = 4.06, SE =.28). In addition, the main effect of the Interactive Gaze was also not significant [F(1, 18) = 3.148, p = .093].

A non-significant interaction effect was observed between the state of the Tactile Feedback and the participant roles [F(1, 18) = 1.475, p = .240]. A non-significant interaction effect was also observed between the state of the Interactive Gaze and the participant roles [F(1, 18) = 1.420, p = .249].

Perceived Behavioral Interdependence (PBI): The predicted main effect of the Tactile Feedback was not significant [F(1, 18) = 1.028, p = .324]. Although not significant, the participants perceived higher PBI when the Tactile Feedback was active (M = 4.65, SE =.21) than it was not (M = 4.53, SE =.23). However, the predicted main effect of the Interactive Gaze was significant [F(1, 18) = 9.875, p = .006, η_p^2 = .354]. The contrast revealed that the participants in the blind-sighted group perceived significantly higher PBI when the Interactive Gaze was active (M = 4.70, SE =.23) than it was not (M = 4.48, SE =.20).

A non-significant interaction effect was observed between the state of the Tactile Feedback and the participant roles [F(1, 18) = 3.103, p = .095]. A non-significant interaction effect was also observed between the state of the Interactive Gaze and the participant roles [F(1, 18) =.222, p = .643].

Closeness: The predicted main effect of the Tactile Feedback was not significant [F(1, 18) =.228, p = .638]. There was also a non-significant main effect of the Interactive Gaze [F(1, 18) =.010, p = .923].

A non-significant interaction effect was observed between the state of the Tactile Feedback and the participant roles [F(1, 18) = 2.056, p = .169]. A non-significant interaction effect was also observed between the state of the Interactive Gaze and the participant roles [F(1, 18) =.086, p = .773].

Summary: The Tactile Feedback did not significantly affect the communication quality in the blind-sighted group. A non-significant interaction effect was also observed between the state of the Tactile Feedback and the participant roles. However, in this group, the participants perceived significantly higher co-presence and PBI when the Interactive Gaze was active than it was not (Fig. 9). The interaction effect further revealed that the sighted participants perceived significantly higher PMU when the Interactive Gaze was active than it was not (Fig. 10).

3) VIDEO ANALYSIS

We observed the experimental videos to record who initiated the conversation in each test. Based on the hypotheses, we reported video data from two aspects: (1) interventions in all participants, and (2) interventions in the blind-sighted group.

In the video analysis, a $2 \times 2 \times 2 \times 2$ mixed-design ANOVA was conducted by using the Tactile Feedback (active, non-active) and the Interactive Gaze (active, non-active) as the within-subjects factors and the conversation groups (blind-sighted, blindfolded-sighted) and the participant roles (the non-sighted participants, the sighted participants) as the

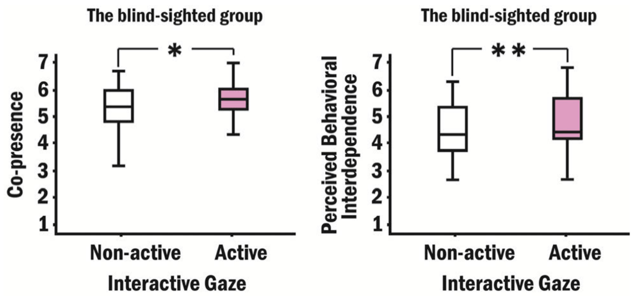

FIGURE 9. Boxplot of the main effect of the interactive gaze on the participants' co-presence (left figure) and PBI (right figure) in the blind-sighted group. Significant group difference; * $p < .05$, ** $p < .01$.

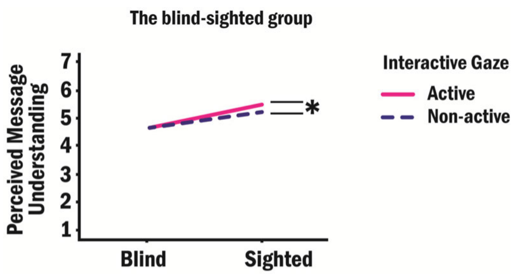

FIGURE 10. Interaction effects between the participant roles and the interactive gaze on the participants' PMU in the blind-sighted group. Significant group difference; * $p < .05$, ** $p < .01$.

between-subjects factors. T_a refers to the average number of times to initiate the conversation.

Interventions in All Participants: There was a non-significant main effect of the Tactile Feedback on T_a [F(1, 36) =.062, p = .805]. The predicted main effect of the Interactive Gaze on T_a was also not significant [F(1, 36) =.039, p = .844]. A significant interaction effect was observed between the state of the Tactile Feedback and the participant roles [F(1, 36) = 10.490, p = .003, η_p^2 = .226]. The contrast revealed that the non-sighted participants had much bigger T_a when the Tactile Feedback was active than it was not. Accordingly, the sighted participants had much smaller T_a when the Tactile Feedback was active than it was not. A non-significant interaction effect was observed between the state of the Interactive Gaze and the participant roles [F(1, 36) =.039, p = .844].

Interventions in the Blind-Sighted Group: A non-significant main effect of the Tactile Feedback was observed on T_a ($p > .05$). There was also a non-significant main effect of the Interactive Gaze on T_a ($p > .05$). Also, a non-significant interaction effect was observed between the state of the Tactile Feedback and the participant roles ($p > .05$). A non-significant interaction effect was also observed between the state of the Interactive Gaze and the participant roles ($p > .05$).

Summary: The findings demonstrated that the non-sighted participants had much bigger T_a when the Tactile Feedback was active than it was not (Fig. 11). Accordingly, the sighted participants had a significantly much smaller T_a when the Tactile Feedback was active than it was not (Fig. 11).

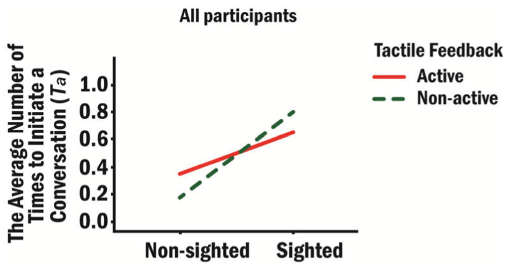

FIGURE 11. Interaction effects between the state of the tactile feedback and the participant roles on T_a.

TABLE 4. The experimental procedure of two conversation groups. An example of abbreviations: BS-B1 refers to a blind participant who has ID number one in the blind-sighted conversation group.

Conversation Groups	Participant Roles	ID
Blind-sighted	Blind	BS-B1, BS-B3, BS-B5, BS-B7, BS-B9, BS-B11, BSB-13, BSB-15, BSB-17, BSB-19
Blind-sighted	Sighted	BS-S2, BS-S4, BS-S6, BS-S8, BS-S10, BS-S12, BS-S14, BS-S16, BS-S18, BS-S20
Blindfolded-sighted	Blindfolded	BFS-BF3, BFS-BF5, BFS-BF7, BFS-BF9, BFS-BF11, BFS-BF13, BFS-BF17, BFS-BF19, BFS-BF21, BFS-BF23
Blindfolded-sighted	Sighted	BFS-S6, BFS-S8, BFS-S10, BFS-S12, BFS-S14, BFS-S16, BFS-S18, BFS-S20, BFS-S22, BFS-S24

However, in the blind-sighted group, the interventions had no significant impact on T_a.

B. QUALITATIVE ANALYSIS

In the qualitative analysis, we used the *conventional content analysis* approach [53] to analyze the participants' comments from the open questions. Total 342 quotes were examined to identify major categories and sub-categories related to users' motivation and attitudes towards the system, their perceptions towards the function of the system and design suggestions. The ID of the participants for exemplary quotes is presented in Table 4.

1) INTEREST

We collected 65 quotes regarding the participants' interests towards the system. Most of the participants' quotes (57 quotes) expressed a great interest towards the Social Glasses system (e.g., "a good idea," "innovative," "funny" and "magic"). They explained the reasons for showing interests as below:

Tactile Feedback: Eighteen quotes mention the tactile feedback could benefit the non-sighted participants. Example quotes are: "Tactile feedback makes me feel less nervous to talk with sighted people" (BS-B15); "Tactile feedback enables me directly and exactly to feel the attention from my conversation partner" (BFS-BF9); "Let a blind person perceive the presence of the conversation partner" (BFS-S12); "Because of the tactile feedback, I feel connected with my conversation partner" (BFS-BF13).

Interactive Gaze: Eleven quotes mention that the Interactive Gaze positively influenced sighted participants.

Example quotes are: "I cannot help interacting with a person with Interactive Gaze, and I want to know what he is thinking about" (BFS-S24); "Interactive Gaze can influence my mood when I talk with a blind person" (BS-S8).

The System: Fourteen quotes mention that the system could positively affect face-to-face communication between blind and sighted people. BS-S16 said, "The system makes me feel closer to communicate with the conversation partner. It is helpful to establish the eye-to-eye communication."

Nevertheless, eight quotes mention that the participants were not interested in the system. Some reasons are given below:

"If sighted people know the conversation partner is blind, they will not request that person to establish the eye-to-eye communication" (BFS-BF19).

Some participants reported that they did not feel too much about the vibration: "In the test, I do not focus on the wristband, so how many times of the vibrations are unknown to me" (BFS-BF17).

2) ATTITUDES

We collected the participants' positive and negative comments (115 quotes) towards the system. The positive category consists of three sub-categories: (1) Tactile Feedback, (2) Interactive Gaze, and (3) the system.

Tactile Feedback: Twelve quotes mention that the participants liked the Tactile Feedback. As stated by BFS-BF8, "It provides me with the feedback, so I can realize that my conversation partner is interested in my speaking." "The tactile feedback helps me realize that how many times my conversation partner looks at me" (BS-B13).

Interactive Gaze: Eight quotes mention that the participants liked the Interactive Gaze could simulate eye gestures of a blind person. Example quotes are: "I can see the eyes of a blind person" (BS-S8), and "Interactive Gaze guided me to have the eye contact with a blind person" (BFS-S10). Five quotes describe the eye gestures of the Interactive Gaze looked real, vivid and natural. Two quotes mention that the participants felt curious about the simulated eye gestures.

The System: Twenty-eight quotes mention the advantages of the system. The example quotes are: "The system benefits us to make friends with sighted people" (BS-B17). "We could communicate efficiently by using this system" (BS-S6). "I can realize whether my partner cares me through the system" (BFS-BF23).

The negative category has three sub-categories: (1) Interactive Gaze, (2) usability, and (3) physical appearance.

Interactive Gaze: Twenty-three quotes describe the disadvantages of the Interactive Gaze. For example, "The size of the simulated eyes is too large, so I am easily distracted" (BFS-S24), and "I do not think the Interactive Gaze can correctly express the mood of blind people. It only simulates the eye appearance" (BFS-S12).

Usability: Twenty-three quotes mention the glasses device was heavy, non-portable and uncomfortable to wear. As stated by BS-B13, "My eyes feel uncomfortable when I wear the Social Glasses. I need a long time to adjust to it."

Physical Appearance: Eleven quotes mention the participants disliked the physical appearance of the Social Glasses. The example quotes are: "The shape of the glasses is not suitable for the daily use" (BFS-BF5); "I feel uncertain about the shape of the Social Glasses in sighted people's eyes, so I am not confident in wearing it" (BFS-BF13).

3) FUNCTIONS

Sixty-five quotes claimed the function of the Social Glasses system was very useful, while 14 quotes expressed the opposite idea. The "useful" category consists of three subcategories: Interactive Gaze, Tactile Feedback, and general positive comments.

Interactive Gaze: Most of the participants praised the Interactive Gaze for its ability to simulate the eye gestures for blind people, enhancing their feelings and personalities in conversations. The example quotes are: "In the conversations, I feel I just talk with a normally sighted person. I can see his eyes clearly" (BFS-S8); "Interactive Gaze promotes us to establish an equal communication" (BFS-S18); "You can discern whether a blind person is interested in your speaking through the eye contact" (BFS-S16).

Tactile Feedback: Most of the participants claimed that the Tactile Feedback was an indicator of the engagement in conversations. Besides, it provided the participants with a sense of security. The example quotes are:

"When I feel the vibration, I know the conversation partner is looking at me. I am more willing to speak to him. If there is no vibration, I guess he is distracted. At that moment, I am not willing to speak anymore" (BFS-BF21).

"I feel I speak more than usual" (BS-B5).

"Without the Tactile Feedback, I feel the conversation partner is far away from me. I cannot see, so I am eager to have a sense of safety. The vibration makes me feel safe. I feel the psychological distance between us becomes shorter" (BFS-BF13).

General Positive Comments: Example quotes are: "overcome communication barriers," "express a friendly attitude," "enliven the atmosphere of communication" and "enhance the mutual presence."

Fourteen quotes mention that the participants did not think the system was useful. The example reasons are: "helpfulness for the conversation," "worried about the appearance of the Social Glasses," and "distract the attention." BS-B13 also emphasized, "I do not perceive too much of vibrations during my speaking. I feel the vibration intensity is a little weak. For example, if I am moving the body or become engaged in an exciting topic, I will ignore such tiny signals."

4) DESIGN SUGGESTIONS

We collected 83 quotes regarding design suggestions, which consisted of five sub-categories: (1) gaze simulation, (2) vibration and others, (3) sensing multiple nonverbal signals, (4) physical appearance and (5) additional functions.

Gaze Simulation: Most of the participants required realistic and natural gaze simulation to provide customized eyes and diverse eye gestures. The example quotes are: "I wish the Social Glasses can display diverse eye gestures to match different facial expressions" (BFS-S8). "The simulated eyes can be customized based on the personality and the facial appearance of blind people" (BFS-S20).

Vibration and Others: Twelve participants suggested improving the vibration of the wristband. Ten participants mentioned transferring gaze signals to other types of signals, such as auditory signals, color, lights, or temperature. The example quotes are given below:

"The vibration intensity should be gentler (e.g., a ring device for the finger is better than a tactile wristband). A tiny vibration can make me feel relieved" (BFS-BF21).

"Different vibration patterns can match different eye gazes. If someone is looking at me, the wristband will vibrate only once; if someone is staring at me, the wristband will keep vibrating. The continuous vibration does not bother me" (BS-B15).

"The growing darker color displayed on the Social Glasses can show an increasing intimacy between two partners" (BFS-BF9).

"If someone is approaching me, the Social Glasses will become warm" (BFS-BF13).

Sensing Multiple Nonverbal Signals: The participants expected the system to sense multiple nonverbal signals, including facial expressions, body gestures, distance and eye movements. Some participants also mentioned to expand the sensing area of the system, rather than limited to the Social Glasses area. The example quotes are:

"I want to perceive facial expressions and the mood of my conversation partner (e.g., four to five typical facial expressions)" (BS-B7).

"I want to know body gestures of the conversation partner. For example, does she lean forward or backward during my speaking? If receiving such information, I can infer that whether she is interested in my speaking" (BFS-BF13).

"The expanded sensing area includes the face, foot, or any place of the body, so I can realize that someone is looking at which part of my body" (BS-B13).

Physical Appearance: The participants presented several expected features of the system, including the invisible design, portability, mobile device, and wearability. The examples are: "The physical appearance of the Social Glasses is expected to be similar to the object seen in daily livings (e.g., a pair of dark sunglasses)" (BFS-BF19); "Glasses device and the tactile wristband are separate two parts, which are inconvenient to wear. The system should combine the glasses with the tactile feedback" (BS-B13).

Additional Functions: The participants suggested that new functions could be added to this system such as voice navigation, voice photography and color recognition. The examples are: "I wish the system can take photos and videos at all times and places" (BS-S16); "Different vibration patterns can stand for different colors. A long and strong vibration can stand for the bright color, while a short and weak vibration for the dark color" (BS-B15).

VI. DISCUSSION AND CONCLUSION

A. THE EFFECT OF TACTILE FEEDBACK AND INTERACTIVE GAZE

1) ALL PARTICIPANTS

(H1) The quantitative results demonstrated that the Tactile Feedback was effective to increase the communication quality, which performed a significantly positive effect on the participants' co-presence and PAU. The qualitative results also supported this hypothesis. Most of the participants held the positive attitudes towards the Tactile Feedback. For example, BS-B15 stated that the Tactile Feedback could make her feel less nervous when talking with a sighted person. Another important reason is the Tactile Feedback can provide a sense of safety for the non-sighted participants. As stated by BFS-BF13, the Tactile Feedback decreased her anxiety in darkness and shortened the psychological distance between two people.

The quantitative results from the questionnaires demonstrated a non-significant interaction effect between the state of the Tactile Feedback and the participant roles. However, the video analysis revealed that the non-sighted participants initiated more conversations when the Tactile Feedback was active than it was not. The findings showed that the Tactile Feedback effectively promoted the non-sighted participants to be more active in conversations. Accordingly, the sighted participants had fewer times to initiate conversations when the Tactile Feedback was active than it was not.

(H2) The quantitative results strengthened our confidence that the Interactive Gaze positively affected the communication quality. In the qualitative findings, most of the participants thought that the Interactive Gaze provided the visual feedback that motivated them fully engaged in conversations. It also helped sighted people overcome possible negative feelings to the unattractive eye appearance of blind people. Vinciarelli *et al.* [15] suggested that the physical appearance is one of the social signals, which closely associates with the attractiveness. Thus, the Interactive Gaze is helpful to improve the physical appearance of blind people. As stated by a sighted participant (BFS-S8): "[...] I feel I am talking with a normally sighted person."

A significant interaction effect was observed between the state of the Interactive Gaze and the participant roles. The sighted participants perceived significantly better communication quality when the Interactive Gaze was active than it was not. Based on the quantitative findings, we also found that the intervention of the Interactive Gaze had a greater impact on the communication quality than the Tactile Feedback. We concluded the reasons as below:

The Interactive Gaze has a positive impact on the sighted participants, because they are very familiar with the gaze and eye contact in their daily living. They well understand the importance of the gaze and eye contact in face-to-face communication. In the experiments, they can directly see the Interactive Gaze displayed on the Social Glasses. Since the sight is often viewed as the dominant modality in five senses [54], the visual feedback of the Interactive Gaze is very effective and straightforward for all sighted participants.

Compared with the Interactive Gaze, the Tactile Feedback has a weaker impact on the communication quality for the non-sighted participants. The possibility is blind people have a fuzzy understanding regarding the gaze behaviors [55]. For the blindfolded participants, although they well understand the gaze and eye contact, they still need some time to be familiar with the relationship between the gaze and the tactile signal [56].

2) THE BLIND-SIGHTED GROUP

In this section, we discuss the findings of the blind-sighted group. Our findings did not support (**H3)** but supported (**H4**). In the blind-sighted group, the participants perceived significantly higher co-presence and PBI when the Interactive Gaze was active than it was not. More precisely, the sighted participants perceived significantly higher PMU when the Interactive Gaze was active than it was not. We also found that the blindfolded-sighted group demonstrated to be more sensitive to the interventions of the Interactive Gaze and Tactile feedback than the blind-sighted group. The Interactive Gaze has a positive impact on the communication quality of the blindfolded-sighted group, but it has a smaller impact on the blind-sighted group. Some factors may influence the communication quality of the blind-sighted group. For instance, the level of the blind participants' spoken language and their passive strategies in conversations. We observed that the spoken language of some blind participants was not very good, probably causing the impatience from their sighted partners. Besides, most blind participants adopted a passive strategy (such as listening) in conversations. The possibility is that they were hesitant to initiate a conversation. According to Griffin's Uncertainty Reduction theory [18], in face-to-face communication, blind people are uncertain about attitudes of sighted people due to a lack of visual information. They are unsure about the consequences, such as how a sighted person reacts to them.

Overall, we demonstrate that our system positively affects the communication quality in dyadic conversations, especially for the blindfolded-sighted group. We might consider extending our target users to "blindfolded people." Such people do not have the sight, but they experience and well understand the gaze and eye contact. For example, older adults gradually lost their sight due to the growing age.

B. DESIGN IMPLICATIONS

In the interviews, we asked the participants to present their ideas and suggestions to the Social Glasses system. We summarize the findings and present design implications.

1) INVISIBLE DESIGN

Qiu [61] presented the vision of the calm technology: "The most profound technologies are those that disappear. They weave themselves into the fabric of everyday life until they are indistinguishable from it" (p.1). This notion informs the design trend regarding the physical appearance of the system. In this study, the participants required the thickness of the Social Glasses was the same as the ordinary glasses, and the appearance of the tactile wristband was like a real sports bracelet. To make the Social Glasses thinner, lighter and "invisible" to people, soft OLED screens may provide an option for our future design.

2) THE "UNCANNY VALLEY" EFFECT

The Uncanny Valley effect [62] describes the negative emotional reaction of a human towards a humanlike robot or prosthesis. The more humanlike characteristics a prosthesis has, the more likely it will be accepted by humans. However, if the similarity to humans reaches a certain point, the affinity will quickly become a strong disgust. In this study, we directly used videos of the realistic human's eyes for the Interactive Gaze design, which was taken from Charon [63]. Some participants reported that the eye appearance displayed on the Social Glasses was too realistic and even let them feel horrible. The Uncanny Valley effect may help explain their perceptions. In our future design, we attempt to use less humanlike eye appearance to improve the Social Glasses (e.g., the suitable animated eyes).

3) INCREASIND THE VIBRATION INTENSITY

In this study, we found a difference of perceiving vibration intensity between blind and blindfolded participants. Due to sensory compensation, blind people developed enhanced tactile acuity for their lack of vision [64]. Initially, we predicted that because of being more sensitive to the tactile feedback, the blind participants would need the lower vibration intensity than the blindfolded participants. However, we were surprised to see that most blind participants liked the strong tactile feedback to perceive the "eye contact." As stated by BS-B17, she thought the vibration feedback from the tactile wristband was too tiny to perceive, especially in a conversation scenario. She did not think increasing the vibration intensity could disturb her. Strong vibrations enabled her to increase the confidence in speaking. Some participants also reported that strong vibrations helped increase a sense of security. Since blind people cannot see anything in the darkness, they particularly concern about their security. This phenomenon was also observed from our prior work in Hong Kong [65].

4) EXPANDING THE SENSING AREA

Most of the blind participants wished to expand the sensing area rather than restrict in the glasses area. They envisioned the system to provide them with the tactile feedback when a sighted person was looking at their face or body. In our study, most blind participants reported that they were born blind or became blind at a very young age. They did not have an explicit understanding of the eye contact. In their opinions, the eye contact was like eye-to-face or eye-to-body communication. Also, the corresponding tactile feedback could allow them to keep alert if the sighted person was looking at their face or body.

5) SENSING MULTIPLE NONVERBAL SIGNALS

In addition to perceiving the gaze, the blind participants wished to know more nonverbal signals from conversation partners. Such nonverbal signals included facial expressions (e.g., smile or frown), body gestures (e.g., nod or shake the head), hand gestures (e.g., thumbs up) and the distance towards the conversation partner. For instance, one participant mentioned that if a teacher's voice pretended to be calm as usual, she was uncertain about his intention. If she could perceive his facial expressions and small gestures as well, she would be easy to realize his real intention. The envisioned system is expected to capture the multiple sensory inputs in face-to-face communication. It can extract many social features of sighted partners (e.g., facial expressions, age, gender, body gestures, head pose, distances, and orientation). The system will select and convert necessary social features to blind people. Besides the tactile feedback, we also consider using the auditory feedback to deliver more accurate information to blind people.

C. LIMITATIONS AND FUTURE WORK

In this study, there are some limitations. First, we did not well balance the participants' age, education background and the level of spoken language for the between-group test. For example, we can include age and gender as co-variates. We should well balance the participants' age, education background, and others in profiles information in our future work. Second, we used questionnaires to measure the communication quality of both blind and sighted people. We did not analyze the objective gaze data from sighted participants. In future work, we will analyze gaze data, and explore the relationship between the questionnaire and the objective fixation data, to generate more interesting findings. Third, the blind participants might not well understand the image questionnaire, so we did not get any significant results from an adapted Inclusion of Other in the Self (IOS) Scale [51]. Fourth, in our study, gaze timing of the Social Glasses were predetermined by the findings from social psychology [66] and the existed gaze model applied in human-agent interaction [38]. We wish to know whether such approach is worth to be continued. Our positive findings encourage us to explore a more sophisticated gaze model for blind people in future work. Fourth, in this experiment, we only tested a two-person conversation scenario, which was considered as the smallest social group [67]. In our future work, we will test the Social Glasses in a multi-party conversation scenario. For instance, a blind person joins a group meeting with three sighted colleagues. All people sit in a circle and a 360-degree camera is located at the circle center to detect the gaze and facial expressions from sighted people around. The blind person can perceive the gaze from his colleagues and send the "gaze reaction" accordingly.

TABLE 5. Participants' age.

Conversation Groups	N	M	SD	Minimum	Maximum
Blind-sighted	20	16.55	.83	15	18
Blindfolded-sighted	20	23.45	2.67	19	30

TABLE 6. Participants' gender.

Conversation Groups	Gender	N
Blind-sighted	Male	12
	Female	8
Blindfolded-sighted	Male	8
	Female	12

TABLE 7. Participants' education background.

Conversation Groups	Education	N
Blind-sighted	The third grade	1
	The eighth grade	9
	The tenth grade	10
Blindfolded-sighted	Bachelor	7
	Master	12
	PhD student	1

In summary, this study has the following contributions:

(1) The tactile wristband was added to the Social Glasses system, which helped the blind person to perceive "eye contact" in social interactions.

(2) Empirical evidence is provided that the Tactile Feedback and the Interactive Gaze positively influence the communication quality in a dyadic-conversation scenario.

(3) The Interactive Gaze has a greater impact on the communication quality than the Tactile Feedback.

(4) We also present design suggestions, considerations, and opportunities for improvement of the smart glasses' technology applied in social interactions.

APPENDIX

Descriptive data (Table 5-7) about profiles information (i.e., age, gender, and education background):

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