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Social Glasses: Simulating Interactive Gaze for Visually Impaired People in Face-to-Face Communication

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ABSTRACT

Eye contact is crucial in social interactions, linking with sincerity and friendliness. However, blind people cannot see and make eye contact when they communicate with sighted people. It influences the involvement of blind people in blind-sighted conversations. Based on this context, we implemented Social glasses with an eye-tracking system, aiming to improve the communication quality between blind and sighted people in face-to-face conversations. Social glasses attempts to simulate the appropriate gaze for blind people, especially establishing the "eye contact" in blind-sighted conversations. To evaluate the impact of the interactive gaze displayed on the Social glasses, we performed dyadic-conversation tests under four experimental conditions (No Gaze, Constant Gaze, Random Gaze, and Interactive Gaze) for 40 participants. Quantitative results showed that the Interactive gaze has a positive impact on improving the communication quality between blind and sighted people, which were consistent with a qualitative analysis of the participants' comments.

1. Introduction

In social psychology, many investigations suggest that high eye contacts link with sincerity and friendliness, and low eye contacts often with insincerity and nervousness (Arndt & Janney, 1987; Cook & Smith, 1975; Kleck & Nuessle, 1968). People who look at others 15% of the time are considered as cold and lacking confidence (Cook & Smith, 1975; Kleck & Nuessle, 1968). However, blind people cannot see and make any eye contact in blind-sighted conversations. Due to a lack of the eye contact, blind people often experience communication breakdown in conversation scenarios, which leads to feelings of social isolation and low self-confidence (Hersen et al., 1995; Kleck, Ono, & Hastorf, 1966; Naraine & Lindsay, 2011). According to Kemp and Rutter (1986), blind and sighted people behaved differently in face-to-face conversations. Blind people were less confident than sighted people to share their feelings in conversations. Due to a loss of vision, they became introverted, submissive and with low confidence in communication and activity.

In some cases, the eye appearance of blind people seems unattractive and often with deformities. Accordingly, their facial appearance might be less appealing to sighted people (Van Hasselt, 1983). The attractiveness of a person's appearance influences his/her social acceptance (Young & Cooper, 1944). Van Hasselt (1983) suggested that a better-looking person has a more extensive social network. Therefore, the eye and facial appearance of blind people could influence their social acceptance. Besides, some blind people suffer an eye illness that prevents them from controlling. In face-to-face communication, inappropriate eye gestures of blind people may cause misunderstandings from sighted conversation partners. Because of uncomfortableness, strangeness, and uncertainty of blind people's feelings, the responses of sighted people are stereotyped and over-controlled when they interact with blind people (Kleck et al., 1966). Van Hasselt (1983) suggested that attitudes of sighted people make blind people feel themselves "special", which makes it difficult to establish an equal relationship in communication. In prior work, Qiu, Hu, et al. (2015) interviewed 20 blind participants regarding their difficulties and needs in social interactions. The participants expressed great interests in the concept design of the glasses system for gaze simulation. If they have the same "gaze reaction" in social interactions, they will look the same as sighted people. Blind people want to be treated as normal and therefore they need proper support. This situation is similar to one in which a person who has lost one leg, but has a prosthesis that allows him to walk.

Therefore, we focus on how to develop a device for blind people to improve the communication quality between blind and sighted people in social interactions. We also want to know whether the device is better than the dark sunglasses (i.e., no gaze condition) that some blind people use in social interactions, since the deformities of their eye appearance might make others around them feel uncomfortable, especially in social settings. Besides, some of them also need dark sunglasses to protect their eyes from certain harmful components of sunlight such as prolonged exposure to UV rays.

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Based on this motivation, we introduce our prototype named Social glasses, aiming at simulating the gaze for blind people, as well as creating the "eye contact" in blind-sighted conversations. In contrast to other assistive systems, Social glasses also satisfy the needs of sighted people in "eye-to-eye communication", to improve the overall communication quality in blind-sighted conversations.

2. Theoretical background

As social beings, humans have a fundamental need to communicate, to form, maintain and enhance social relationships (Baumeister & Leary, 1995). According to Abraham Maslow's hierarchy (Runco, 2014), human needs have several levels that include basic needs, psychological needs, and self-fulfillment. Once the basic needs are met, a person will strive to satisfy the need for love and belonging in social interactions. Recent developments in multisensory research, computer vision, and wearable technology have introduced many assistive technologies for blind people. The majority of the assistive systems still aim at solving basic needs of blind people, such as navigation (Dunai, Fajarnes, Praderas, Garcia, & Lengua, 2010; Ivanchenko, Coughlan, & Shen, 2008), graphic access (Yusoh et al., 2008) and Braille displays (Prescher, Weber, & Spindler, 2010). However, as Shinohara and Wobbrock (2011) suggested, "Research involving assistive technologies generally focuses on functionality and usability, yet technology use does not happen in a social vacuum." Therefore, supporting the social needs of this group of users is important as well.

2.1. Assistive systems in social interactions

Assistive systems in social interactions are getting increased attention. Many studies describe systems for blind people which can identify conversation partners. Krishna, Little, Black, and Panchanathan (2005) presented a wearable device named iCare Interaction Assistant, to help blind users during social interactions. Based on the face recognition technology, it aims at identifying sighted conversation partners. Kramer, Hedin, and Rolkosky (2010) described a face recognition tool to help blind users identify people during group meetings. It is worn by a blind user, and will identify the faces of co-works and colleagues from a database. Once a face is identified, the blind user can hear that person's name via a wireless earpiece. Neto, Grijalva, and Maike (2017) used a Microsoft Kinect sensor as a wearable device to help blind people recognize and localize others. The results showed the system provided a significantly higher accuracy rate than traditional face recognition methods publicly available. Beyond face recognition, some studies have presented assistive technologies which can help blind people identify their conversation partners' facial expressions (Buimer et al., 2016; Krishna & Panchanathan, 2010), behavioral expressions (e.g., head movements Anam, Alam, & Yeasin, 2014), and other nonverbal signals in social interactions (number of people present, their age and gender distributions (Tanveer & Hoque, 2014). Although gaze signals are very important in social interactions, few studies explored how to communicate crucial gaze information to blind people during face-to-face conversations, and how to help blind people react to their sighted conversation partners with a simulated gaze.

2.2. Bionic eyes

One of the emerging trends of the assistive technology regarding the gaze is "bionic eyes." Bhowmick and Hazarika (2017) suggested that the development of "bionic eyes" is a groundbreaking strategy for returning some functional vision to visually impaired people. It aims at improving their independence and quality of lives. "Bionic eyes" often refers to the visual prosthesis, to provide a complete and fundamental solution for blind people. The original idea of "bionic eyes" is not new and has been explored for many years in laboratories. In this research area, the most common technique is "to electronically stimulate the visual pathway with a visual prosthesis or bionic eyes" (Lewis et al., 2016). In addition to academia, the Second Sight Company has devoted much effort toward the development of "bionic eyes." It attempts to test whether an array of electrodes placed on the surface of the brain can restore limited vision to people with partial or even complete blindness (Mullin, 2017).

Although the "bionic eyes" technology is promising, it still has some limitations. Firstly, it needs much time to verify the feasibility and safety by many rounds of clinical trials in humans. The "bionic eyes" and other kinds of the visual prosthesis are implantable, invasive, and high cost. They are not feasible to become popular at the current stage. Secondly, it enables blind people with a certain form of blindness to perceive simple light patterns, however, it leaves open the question of how to make such patterns meaningful to blind people. Finally, but most importantly, it cannot provide the visual reaction. It cannot provide the appropriate visual gaze for blind people in social interactions.

2.3. Gaze simulation

Since we have not found related work simulating gaze for blind people, we have borrowed the practical approaches to designing and modeling the gaze between humans and the virtual agents (avatars). In HCI, simulating gaze behaviors has been extensively studied in the context of designing the humanlike virtual agents. We summarized the studies in this field into two categories: (1) reactive-gaze mechanisms, and (2) turn-taking strategy, which are highly relevant to our design.

2.3.1. Reactive-gaze mechanisms

The reactive gaze employ a head or eye tracking system. A person's head orientation or gaze direction can trigger an instant response from the virtual agent. Therefore, a "two-way" interaction is simulated between a human and a virtual agent. Kipp and Gebhard (2008) used head-tracking technology to implement a semi-immersive system named IGaze to explore reactive gaze between humans and virtual agents. IGaze has three gaze strategies: Mona Lisa strategy (continuous gaze following), dominant strategy and submissive strategy. The results showed that the dominant and submissive strategies conveyed intended impressions, and the participants positively received the Mona Lisa strategy. Bee et al. (2010) presented an interactive gaze model to improve user experiences in an interactive storytelling scenario. In their interactive gaze model, an eye tracker was employed to enable the interactive gaze of the conversation agent to respond appropriately to the person's gaze. The experimental results demonstrated that the interactive gaze model significantly outperformed the non-interactive gaze and provided the participants with a good user experience.

2.3.2. Turn-taking strategy

Gaze behaviors correlate with turn-taking in conversations. Hirvenkari et al. (2013) suggested, eye contact often correlates with turn exchange in conversations. The turn-taking strategy has been widely employed to control gaze behaviors in virtual agents. Using empirical analysis of dyadic conversations, Cassell, Torres, and Prevost (1999) examined the relationship of gaze behaviors with the information structure and turn-taking in conversations. Based on those empirical findings, they developed an algorithm to guide conversation agents' gaze behaviors. Heylen, van Es, Nijholt, and van Dijk (2005) conducted an experiment to investigate the effects of different gaze behaviors of a cartoon-like talking face on the quality of human-agent dialogs. The results showed that the gaze strategy based on a turn-taking model positively influenced the dialogue quality. Kang, Feng, Leuski, Casas, and Shapiro (2015) examined users' reactions to a virtual human, based on four conditions: (1) animation based on a statistical model while listening, (2) animation with a constant mutual gaze, (3) static image, and (4) no image. Their findings demonstrated that people engaged for a longer amount of time with a virtual human, based on the turn-taking model than with the other three .

Overall, gaze behaviors are very important for designing the virtual agent. They have a crucial impact on the quality of human-agent dialogs. In the current study, we focus on the communication quality in dyadic (two-people) conversations. We simulate the interactive gaze for blind people, and investigate how the interactive gaze affects the communication quality in blind-sighted conversations. To our knowledge, the impact of gaze simulation on the communication quality in blind-sighted conversations has not been investigated so far.

3. Social glasses

The technological solution of the Social glasses was inspired by the AgencyGlass (Osawa, 2014). The prototype was originally designed for a sighted person to decrease the emotional load. It used a keyboard to control basic eye gestures. We incorporated AgencyGlass into the Social glasses system to allow a blind person to react to a sighted person by simulating the appropriate gaze. In our prior work (Qiu, Osawa, et al., 2015), a wearable device was proposed that aimed to create eye-to-eye communication between blind and sighted people in face-to-face conversations. That previous system implemented reactive gaze, which links the eye tracking system with the corresponding eye animations (Qiu, Anas, Osawa, Rauterberg, & Hu, 2016; Qiu, Han, Rauterberg, & Hu, 2018). Whenever the sighted person is looking at the blind person, the Social glasses worn by the blind person will look back, to establish the "eye contact." Currently, We implemented this interactive gaze model of the Social glasses and made the working system available for the user experiments with a dyadic-conversation scenario between a blind person and a sighted person.

3.1. Interactive gaze model

Figure 1a shows an overview of our Interactive Gaze Model, which is based on our previous work (Qiu et al., 2018). This interactive gaze model, combines the eye-contact mechanism (i.e., the reactive gaze) and the turn-taking strategy. Detailed timing of the interactive gaze is carefully tuned, based on the research of dyadic conversations between a human and a virtual agent (Bee et al., 2010; Kendon, 1967).

3.1.1. Eye-contact mechanism

As shown in Figure 1b, whenever the sighted person is looking at the Social glasses, the system reacts to the sighted person with a "look at" eye gesture, and holds it for about one second, to establish the "eye contact." Then it looks away for about four seconds to avoid a dominance for staring too long. One of the four eye gestures (i.e., look up, down, left, and right) are randomly chosen to display a "look away" eye gesture. Figure 1b presents the flow chat of the eye-contact mechanism.

3.1.2. Turn-taking strategy

Figure 1c presents the flow chart of the turn-taking strategy. A sound detector can detect the change in the listening and speaking modes in the conversation flow. The timing of the Social glasses "look at" and "look away" is varied according to whether the blind person is speaking or listening. This strategy is based on the experimental studies of Argyle, Cook, and Cramer (1994), in which they found that people looked more at the conversation partner while listening than speaking. In our system, the Social glasses displays a "look at" eye gesture for two seconds, and then looks away for four seconds, as the blind person is speaking. If the blind person is listening, the Social glasses displays a "look at" eye gesture for three seconds and then looks away.

3.2. System implementation

In this section, we introduce the implementation of the interactive gaze model for the Social glasses system. The Social glasses will be worn by a blind person. Two sensors drive gaze animations of the Social glasses. The Eye Tribe[1] tracker detects gaze signals from a sighted person, and the sound detector of the social glasses detects audio signals from a blind person when she is speaking. The Eye Tribe tracker is used to detect the gaze signal from the sighted person for implementing the eye-contact mechanism, while the sound detector was added to the earlier design (Qiu et al., 2016) for the turn-taking strategy. In a dyadic-conversation scenario, to detect the blind person's speaking clearly, the sound detector is fixed on a flexible rod that can be adjusted to near the mouth of a blind person. The sensitivity of the sound detector is regulated and calibrated only to detect the speaking from the blind person. According to audio information, the system can identify conversation state of the blind person (i.e., the speaking mode or the listening mode).

Overall, the Social glasses system consists of an Eye Tribe tracker, a laptop, two 1.7" micro OLED display modules with

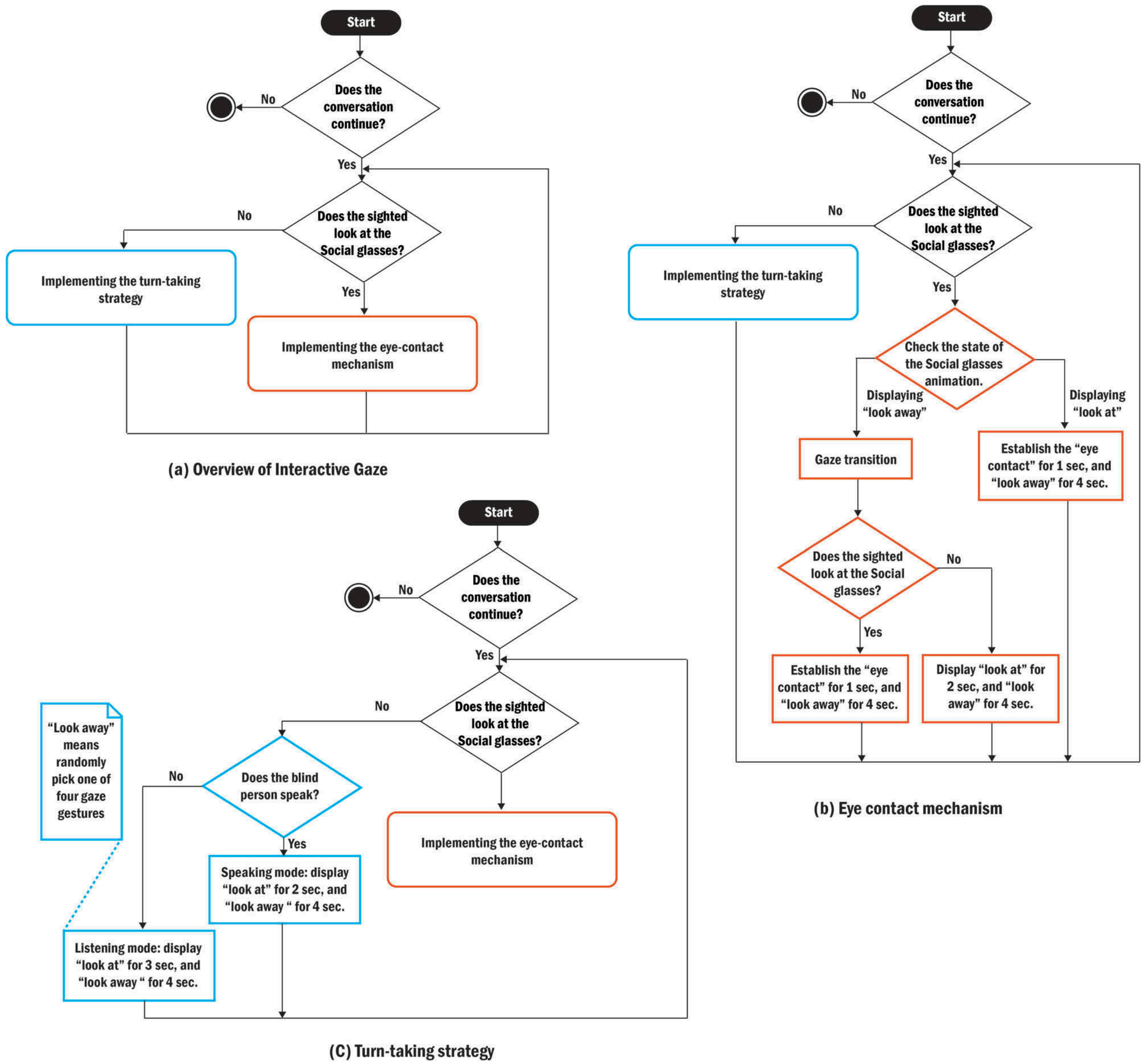


Figure 1. (a) Overview of the interactive gaze model; (b) Eye-contact mechanism; (c) Turn-taking strategy.

an embedded graphics processor, an Arduino microcontroller board, a Bluetooth module, a sound detector module, and a physical glasses-shaped prototype. Figure 2 shows the system overview and the relevant scenario.

For the calibration of the gaze signal from the sighted person, a laptop screen is placed in front of the sighted person, displaying a graphical user interface (GUI) with 15 targeted areas to indicate the point of interest. When the sighted person looks at the target area, the Social glasses system activates the corresponding area to display the red points (Figure 3a). The red dots in Figure 3a indicate that the sighted person is looking at the direction of the target area of the Social glasses. The laptop is removed after calibration (Figure 3b). The similar setup has been used in an interactive-cup system (Anas et al., 2016).

To enable the Social glasses to interact and respond to the sighted person's gaze, the position of the Social glasses was predetermined within the tracking area. When the sighted person looks at the Social glasses, the system sends the command to the Arduino through a wireless Bluetooth connection. The tracker detects the gaze from the sighted person, and if the gaze is in the area of the Social glasses, a command is sent out via Bluetooth adapter from the laptop to a Bluetooth module connected to the Arduino. The Social glasses then displays a "look at" eye gesture to establish the "eye contact" with the sighted. We used human's eye gestures videos (Osawa, 2014) to display on the OLED display. The videos were saved into an SD card with a raw format which is readable by GOLDELOX graphics processors. Figure 3c shows the Social glasses are worn by a person.

4. Experiment

4.1. Aim

This study aims to investigate sighted and blind people's perceptions and reactions to the Interactive Gaze, examining whether the Interactive Gaze affects the communication quality

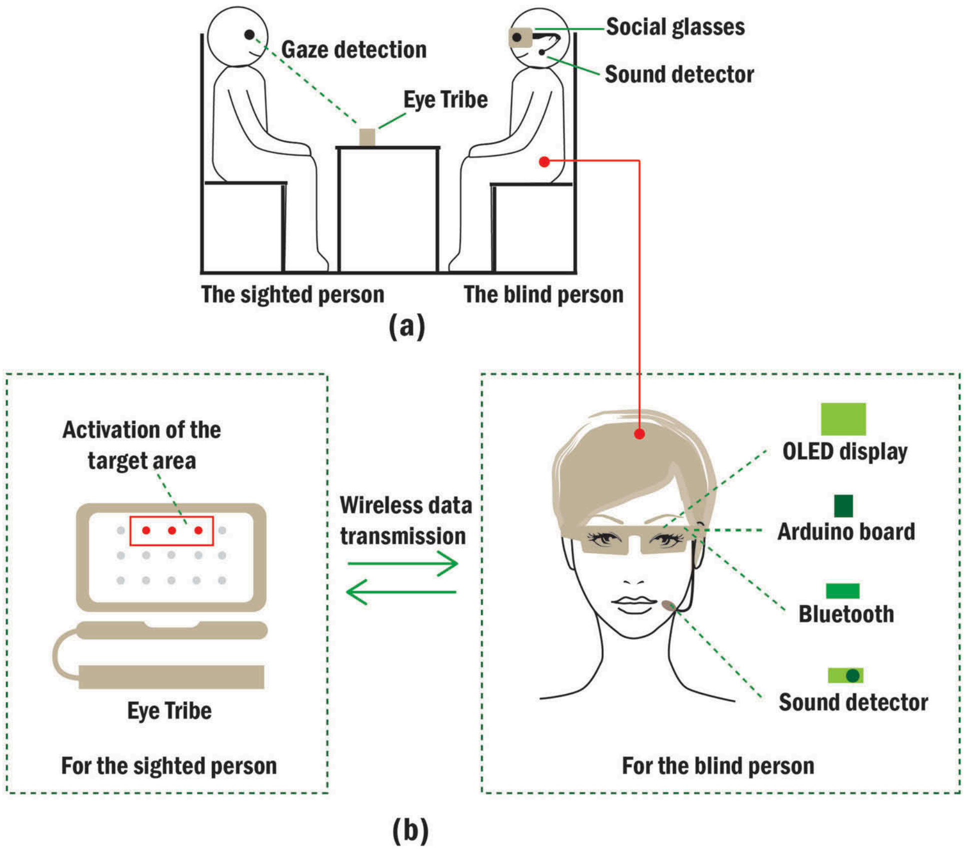


Figure 2. (a) A dyadic-conversation scenario; (b) system overview of the Social glasses.

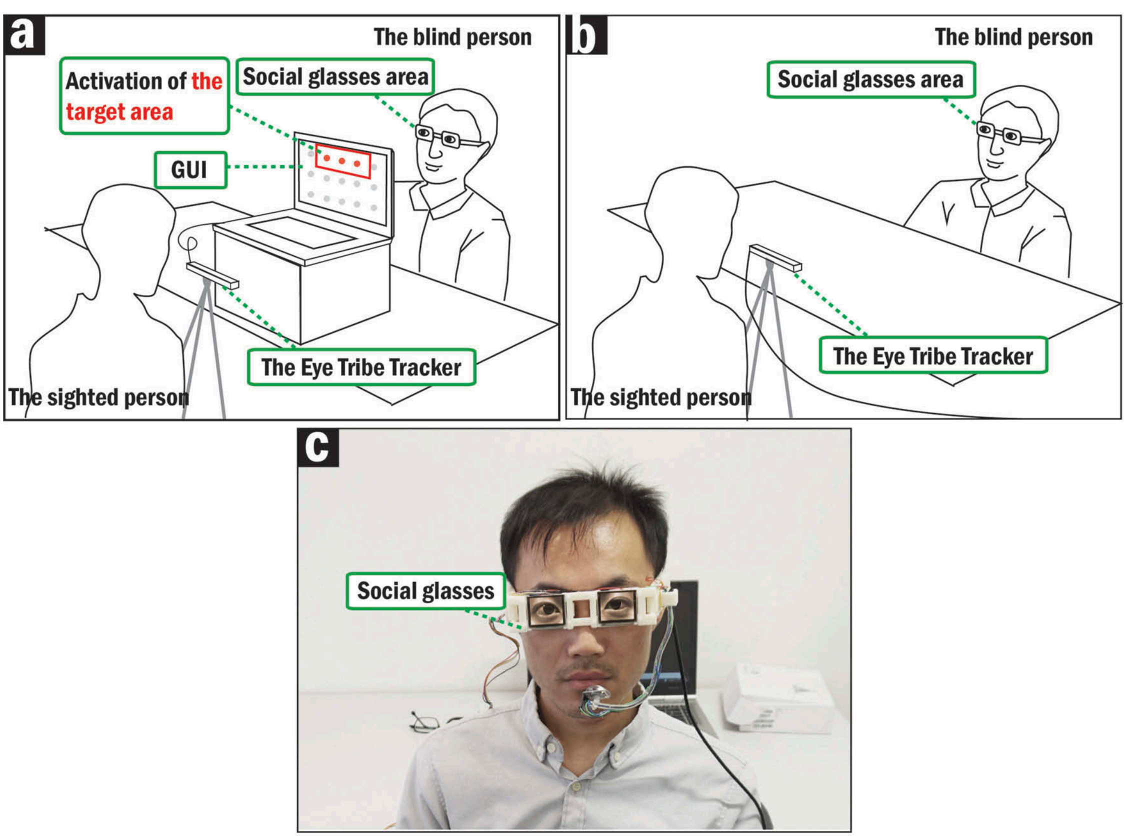


Figure 3. (a) Calibration, (b) remove the laptop after calibration, (c) the Social glasses are worn by a person (with consent).

in blind-sighted conversations. In addition to the Interactive Gaze condition, three control conditions are No Gaze, Random Gaze, and Constant Gaze, which were based on an increasing rate of eye contact from zero (0%) to continuous (100%) (Argyle, Lefebvre, & Cook, 1974). Thus, we formulate the hypothesis that the participants will perceive the higher communication quality in the Interactive Gaze condition than other three conditions.

Besides the real blind participants, we recruited sighted people being blindfolded, namely blindfolded participants, to attend the lab-based experiment. In HCI, many studies substituted the blind participants with the blindfolded participants when studied technical solutions intended for blind people (Moll, Huang, & Sallnäs, 2010; Nikolakis, Moustakas, Tzovaras, & Strintzis, 2000; Yusoh et al., 2008). The reason is sometimes bringing blind people into a specific location for the laboratory experiment is not easy, and the traditional statistic techniques may be difficult to apply if there is a small number of the participants (Sears & Hanson, 2012).

4.2. Experimental design

To test the effectiveness of Interactive Gaze, we compared Interactive Gaze with other three conditions. Thus, the corresponding 4 × 2 × 2 mixed factorial experimental design was proposed, using four gaze conditions (No Gaze, Constant Gaze, Random Gaze, Interactive Gaze) as the within-subjects factor, the conversation groups (blind-sighted, blindfolded-sighted) as the between-subjects factor, and the participant roles (blind and blindfolded participants, sighted participants) as the between-subjects factor.

We recruited 40 participants and made up 20 pairs (i.e., ten blind-sighted vs. ten blindfolded-sighted). Two kinds of pairs followed the similar procedure in the user experiment. In the blind-sighted pair, a blind participant wore the Social glasses and discussed a given daily topic with a sighted participant. They had four conversations with each other, and each conversation lasted around 10 minutes. Four conversations took place under four test conditions of the Social glasses (No Gaze, Constant Gaze, Random Gaze, and Interactive Gaze) with a counterbalanced measures order to avoid the carry-over effects.

In the experimental design, there are three independent variables:

The first independent variable is how the Social glasses displays gaze behaviors. This variable is treated as a within-subject factor. It has four conditions: No Gaze, Constant Gaze, Random Gaze, and Interactive Gaze.

(1) No Gaze: Social glasses only have two black OLED screens. This condition is similar to wearing dark sunglasses.
(2) Constant Gaze: Social glasses displays a "look at" eye gesture.
(3) Random Gaze: Social glasses randomly displays five eye gestures (i.e., look at, up, down, left, and right). The average duration of each state is two seconds.
(4) Interactive Gaze: Social glasses displays the eye gestures based on an interactive gaze model that has been introduced in Section 3.1.

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

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

4.3. Participants

The user experiments were conducted in two locations, Shanghai and Yangzhou in China. For the experiments conducted in Shanghai, only the sighted participants were recruited from Shanghai Jiao Tong University (SJTU) by posting the recruitment information on the university website (tongqu.me) without any particular criterion. For the experiments conducted in Yangzhou, both blind and sighted participants were recruited. The blind participants were recruited from Yangzhou Special Education School (YZSES) under the help of the teachers based on two criteria: (1) blindness should be the only significant handicap, and (2) the students should be registered blind in China Disabled Persons' Federation (China Disabled Persons' Federation [CDPF], 2013). The sighted participants were recruited from Jiangsu College of Tourism (JCT) under the help of the teachers without any particular criterion. All participants were informed about the study and gave their consent to participate. Since this was a non-clinical study without procedures that may lead to risks of harming, and all data were collected anonymously, ethical approval was not sought for the execution of this study (as similar to the situation described in another HCI study by Ivonin et al. (2015)).

The participants were 40 student volunteers in China (M_{age} = 19.35, SD = 2.98, N = 20 females vs. 20 males) with ages ranging from 16–26. The participants were divided into two groups: (1) the blindfolded-sighted group from SJTU, and (2) the blind-sighted group from YZSES and JCT (Table 1). The experiment with the blindfolded-sighted group was conducted in SJTU, and the blind-sighted group was in YZSES.

The participants to be blindfolded were randomly selected in the blindfolded-sighted group. This group consisted of ten pairs with one blindfolded and one sighted in each (M_{age} = 21.65, SD = 2.390, N = 8 females vs. 12 males). The blind-sighted group consisted of ten pairs with one real blind and one sighted (M_{age} = 17.05, SD = 1.191, N = 12 females vs. 8 males). The participants in each pair were matched with the same gender to avoid the heterosexual effect in conversations. Two participants in each pair had a similar age, which might be easier for them to generate discussions. Each participant was compensated 100 CNY at the end of the experiment. The blind participants provided their vision conditions based on their disability certificates from (CDPF,

Table 1. Two conversation groups.

Conversation Groups	Number of Participants	Sight Capacity	University, College and School	Experiment location
Blindfolded-sighted	10	Blindfolded	SJTU	SJTU
	10	Sighted	SJTU	SJTU
Blind-sighted	10	Blind	YZSES	YZSES
	10	Sighted	JCT	YZSES

2013). We converted the vision conditions of the blind participants in mainland China to the visual acuity of WHO standard categories (World Health Organization [WHO], 2008). According to our previous investigation (Qiu, Hu, et al., 2015), none of the participants in these categories can perceive their partner's subtle nonverbal signals (e.g., gaze and eye contact, finger gestures). Instead of vision, the participants could perceive such information through other modalities (e.g., sense of hearing and touch). For instance, the participants could roughly sense a person's facial orientation through his or her speaking (Qiu, Hu, et al., 2015; Qiu, An, Hu, Han, & Rauterberg, 2019). Vision conditions are presented in Table 2. In all participants, 34 participants never knew each other, and six participants knew each other.

4.4. Setup

The participants were divided into pairs to take dyadic conversations. Schematic diagrams of the experimental setup are presented in Figure 4. A blind or blindfolded participant wore the Social glasses and sat in front of a sighted participant. The sighted participant was approximately 1.8m away from the blind or blindfolded conversation partner. It is a comfortable social distance for people sitting in chairs or gathered in a room (Hall, 1963). We aligned the Eye Tribe tracker and adjusted it toward the sighted participant's face for the maximum trackability. The tracker connected to a laptop was installed around 0.5 m away from the sighted participant. To stabilize and track the gaze accurately, we used a comfortable pillow to support the neck of the sighted participant well. The observation camera captured the whole scene. In the experimental setup, we used a USB cable to connect the laptop and the Social glasses rather than the wireless connection. Figure 5 shows a picture taken from the observation camera during the experiment.

4.5. Procedure

The procedure of the experiment is shown in Figure 6. In the experiment, the participants in the blindfolded-sighted pair signed consent forms and completed pre-experimental questionnaires by themselves. In the blind-sighted pair, the blind participant cannot read the consent form due to the blindness. Besides the researcher, a volunteer who was not affiliated with the research team was invited to observe the consent process. The volunteer orally presented the consent form and allowed the blind participant sufficient time for the questions to be asked and answered. With clear understanding, the blind participant had an oral statement: "*I agree to participate in this research. My name is […], and the date is […]*" 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.

After completing the consent forms, the participants filled out the pre-experimental questionnaire regarding the demographic information. Next, the blind or blindfolded participants wore the Social glasses. 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 and the Social glasses during the entire experiment, including answering the questionnaires.

We randomly picked one of the fourteen daily topics from the IELTS oral exam ("IELTS Speaking Module – Part 2 – Sample Topics," 2012). The topics regarding daily lives should be easy for the participants to start a conversation. For example, one of these topics was "*Describe an important choice you have to make in your life.*" We asked two participants in the same pair to share ideas about the topic and gave them three minutes to prepare the topic. Next, we calibrated the eye tracker for the sighted participants, which took less than two minutes. The participants completed the post-experimental questionnaires after a ten-minute conversation. The sighted participant could complete the paper questionnaires. Meanwhile, the researcher orally presented the questionnaire to the blind or blindfolded participants, and completed questionnaires based on their oral answers. In the experiment, the participants had four conversations. Each conversation lasted around 10 minutes, and after each conversation, the participants were asked to answer the post-experimental questionnaires. After completing four conversations and post-experimental questionnaires, we conducted a short interview to collect the participants' comments toward the Social glasses. The conversations were videotaped, and the interviews were audio taped. The overall experiment in the blind-sighted pairs lasted approximately 150–180 minutes, while in the blindfolded-sighted pairs lasted about 120–150 minutes.

Table 2. Vision conditions of the blind participants in the blind-sighted group.

Gender	Age	Vision Conditions (WHO Standard)[a]	Congenital Blindness (Y/N)	Color Perception (Y/N)	Light Perception (Y/N)
F	19	Moderate visual impairment	Y	Y	Y
M	20	Moderate visual impairment	Y	Y	Y
M	17	Moderate visual impairment	Y	Y	Y
M	16	Moderate visual impairment	Y	Y	Y
F	16	Severe visual impairment	N	Y	Y
M	18	Severe visual impairment	N	Y	Y
M	19	Severe visual impairment	Y	Y	Y
M	16	Blindness 3	N	Y	Y
F	18	Blindness 4	N	Y	Y
M	16	Blindness 5	Y	N	N

[a]Vision impairments are sorted from low to high.

4.6. Measurements

According to Biocca, Harms, and Burgoon (2003), a brief description of "*social presence*" is the "*sense of being with another.*" "*Another*" refers to either a human or an artificial agent. In our experiment, we used an adapted version of the "*Networked Minds Social Presence Inventory*" (NMSPI) developed by (Harms & Biocca, 2004). NMSPI includes 36 items. It is composed of six sub-dimensions with a seven-point response scale ranging from one (strongly disagree) to seven (strongly agree) (Table 3).

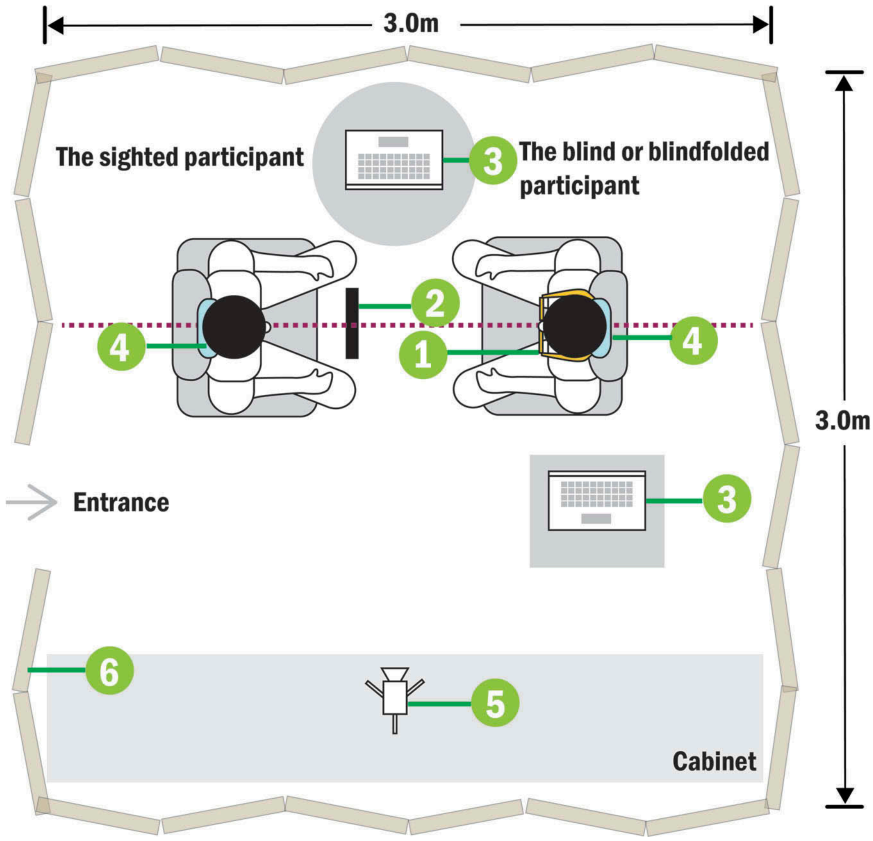


Figure 4. Overhead view of the experimental setup: (1) the Social glasses, (2) the Eye Tribe Tracker, (3) the laptop, (4) the pillow to support the neck of the participant, (5) the observation camera, and (6) the folding screens.

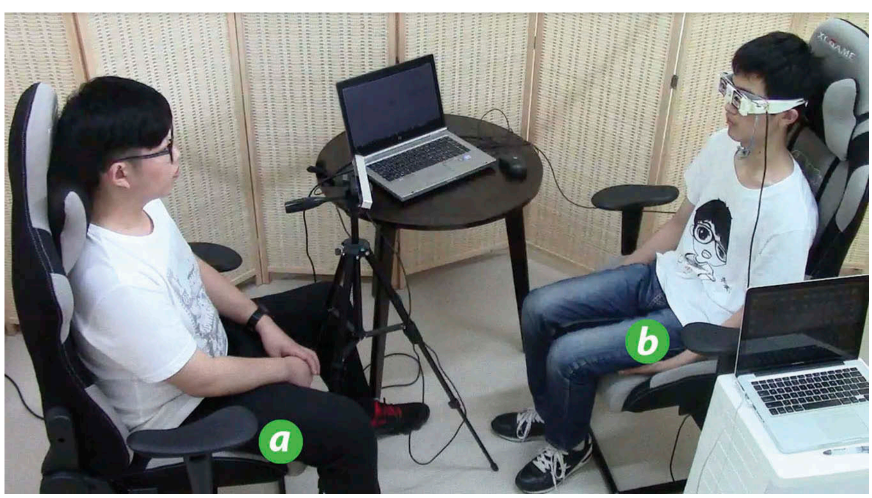
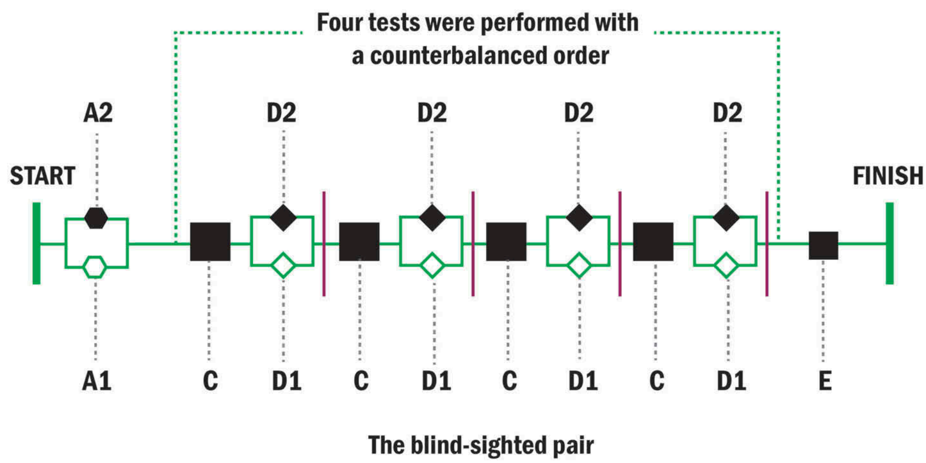


Figure 5. The picture was taken from the observation camera during the experiment: (a) the Eye Tribe detected the gaze from the sighted; (b) a blind participant wore the Social glasses.

Closeness and amount of the circle overlap were strongly related to the degree of love and friendship (Pipp, Shaver, Jennings, Lamborn, & Fischer, 1985). Here we used "*Inclusion of Other in the Self*" (IOS) Scale (Aron, Aron, & Social, 1992) to measure the closeness between two conversation partners. It includes seven increasingly overlapping circle pairs, indicating the distance of the relationship between themselves and their conversation partners. Because the blind and blindfolded participants could not see the circle pairs, we used the percentage of the overlapping from 0% to 90% to match seven options (Figure 7). In the experiment, the researcher orally explained each option to a blind or blindfolded participant.

In addition, we collected the participants' comments from a post-questionnaire. After completing each session in the test, we asked the sighted participants about their perceptions toward the gaze conditions of the Social glasses: "*Your partner wore the Social glasses in conversations. During the conversation, what was your perception when you were looking at the*



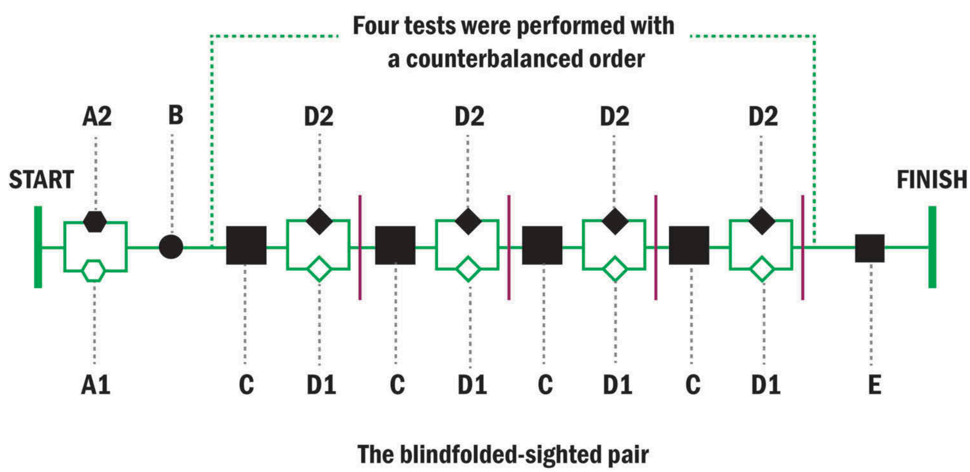


Figure 6. The procedure of the experiment: (A1) read and sign consent forms; (A2) a volunteer helped in the consent process (only for the blind participants); (B) experience being blindfolded (only for the blindfolded participants); (C) test; (D1) complete the post-experimental questionnaire; (D2) the researcher orally presented the questionnaire to the blind or blindfolded participants and completed the questionnaires based on their oral answers; (E) the interview for the open questions.

Table 3. Six sub-dimensions in an adapted version of the networked minds social presence inventory (Harms & Biocca, 2004).

	Sub-dimensions	Descriptions of each sub-dimension	Example item
1	Co-presence	The level of awareness of the partner	I noticed (my partner).
2	Attentional allocation	The amount of attention that a person provides to, and receives from the partner	I was easily distracted from (my partner) when other things were going on.
3	Perceived message understanding	The ability that a person could understand the message from the partner	(My partner) found it easy to understand me.
4	Perceived affective understanding	A person's ability to understand a partner's emotion and attitudes	I could describe (my partner's) feelings accurately.
5	Perceived emotional interdependence	The extent that a person's emotional state affects, and is affected by the partner	(My partner) was sometimes influenced by my moods.
6	Perceived behavioral interdependence	The extent that a person's behavior affects and is affected by the partner	My behavior was often in direct response to (my partner's) behavior.

Social glasses?" Sighted participants are expected to have a better experience when they are looking at the Social glasses in the Interactive Gaze condition than other three conditions. Besides, the participants' qualitative feedback is helpful for us to get some insights for improving the Social glasses.

5. Results

5.1. Quantitative results

The quantitative results consist of two parts: (1) analysis of gaze conditions in all participants, and (2) analysis of gaze conditions in the blind-sighted group. To test the hypothesis, a 4 × 2 × 2 mixed ANOVA was performed. It used four gaze conditions (No Gaze, Constant Gaze, Random Gaze, Interactive Gaze) as the within-subjects factor, conversation groups (blind-sighted, blindfolded-sighted) as the between-subjects factor, and participant roles (blind and blindfolded participants, sighted participants) as the between-subjects factor.

5.1.1. Analysis of gaze conditions in all participants

5.1.1.1. Co-presence. A significant main effect was observed among four gaze conditions [$F(3, 108) = 5.472$, $p = .002$, $\eta_p^2 = .132$]. The contrast revealed that the participants felt

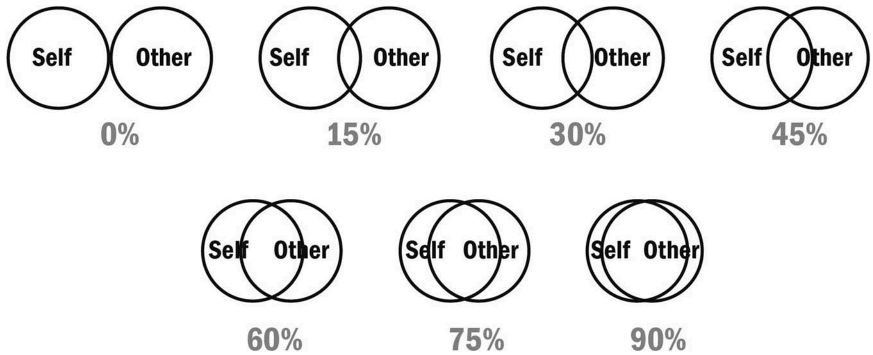


Figure 7. Modified the Inclusion of Other in the Self (IOS) scale (Aron et al., 1992) with the percentage numbers.

significantly higher co-present to use the Social glasses with Interactive Gaze (M = 5.55, SE = .13) than without any gaze (M = 5.09, SE = .13). A significant interaction effect was also observed between gaze conditions and the participant roles [F(3, 108) = 7.461, p < .001, η_p^2 = .172]. It indicated that the participants' co-presence toward the four gaze conditions differed according to the participant roles. For the blind and blindfolded participants, their co-presence was generally the same toward four gaze conditions. For the sighted participants, they felt significantly higher co-present to see the conversation partners with the Interactive Gaze (M = 5.68, SE = .18) and Random Gaze (M = 5.33, SE = .13) than without any gaze (M = 4.68, SE = .20).

5.1.1.2. Attentional allocation. A significant main effect was observed among four gaze conditions [F(3, 108) = 2.837, p = .041, η_p^2 = .073]. The contrast revealed that the participants experienced significantly higher attentional allocation to use the Social glasses with Interactive Gaze (M = 5.19, SE = .16) than Random Gaze (M = 4.82, SE = .14). A significant interaction effect was also observed between gaze conditions and the participant roles [F(3, 108) = 2.968, p = .035, η_p^2 = .076]. It indicated that the participants' attentional allocation toward four gaze conditions differed according to the participant roles. For the blind and blindfolded participants, their co-presence was generally the same toward four gaze conditions. For the sighted participants, they experienced significantly higher attentional allocation to see the conversation partners with the Interactive Gaze (M = 5.00, SE = .23) than Random Gaze (M = 4.22, SE = .23).

5.1.1.3. Perceived Message Understanding (PMU). A non-significant main effect was observed among four gaze conditions [F(3, 108) = 1.451, p = .232]. However, a significant interaction effect was found between gaze conditions and the participant roles [F(3, 108) = 2.721, p = .048]. It indicated that the participants' PMU toward four gaze conditions differed according to the participant roles. For the blind and blindfolded participants, their co-presence was generally the same toward four gaze conditions. For the sighted participants, they experienced significantly higher PMU to see the conversation partners with the Interactive Gaze (M = 5.08, SE = .19) than Random Gaze (M = 4.56, SE = .21).

5.1.1.4. Perceived Affective Understanding (PAU). A non-significant main effect was observed among four gaze conditions [F(3, 108) = 1.643, p = .184]. There was also a non-significant interaction effect between gaze conditions and the participant roles [F(3, 108) = .896, p = .446].

5.1.1.5. Perceived Emotional Interdependence (PEI). A non-significant main effect was observed among four gaze conditions [F(3, 108) = .622, p = .602]. There was also a non-significant interaction effect between gaze conditions and the participant roles [F(3, 108) = .305, p = .822].

5.1.1.6. Perceived Behavioral Interdependence (PBI). A significant main effect was observed among four gaze conditions [F(3, 108) = 3.354, p = .022, η_p^2 = .085]. The contrast revealed that the participants experienced significantly higher PBI to use the Social glasses with Interactive Gaze (M = 5.38, SE = .14) than Constant Gaze (M = 5.00, SE = .18). However, a non-significant interaction effect was observed between gaze conditions and the participant roles [F(3, 108) = 1.603, p = .193].

5.1.1.7. Closeness. A non-significant main effect was observed among four gaze conditions [F(3, 108) = 1.359, p = .259]. There was also a non-significant interaction effect between gaze conditions and the participant roles [F(3, 108) = .791, p = .501].

5.1.1.8. Summary. The results demonstrated that Interactive Gaze was more effective than other three gaze conditions to improve the communication quality. Interactive Gaze positively affected the participants' co-presence, attentional allocation and PBI in conversations (Figure 8 (1)(2)(3)).

A significant interaction effect was observed between gaze conditions and the participant roles. The sighted participants experienced significantly higher attentional allocation and PMU in the Interactive Gaze condition than in the Random Gaze condition (Figure 9). They also experienced significantly higher co-presence in the Interactive Gaze and Random Gaze conditions than in the No Gaze condition (Figure 9 (1)).

5.1.2. Analysis of gaze conditions in the blind-sighted group

In this section, we analyzed the experimental data only from the blind-sighted group. A 4 × 2 mixed ANOVA was conducted,

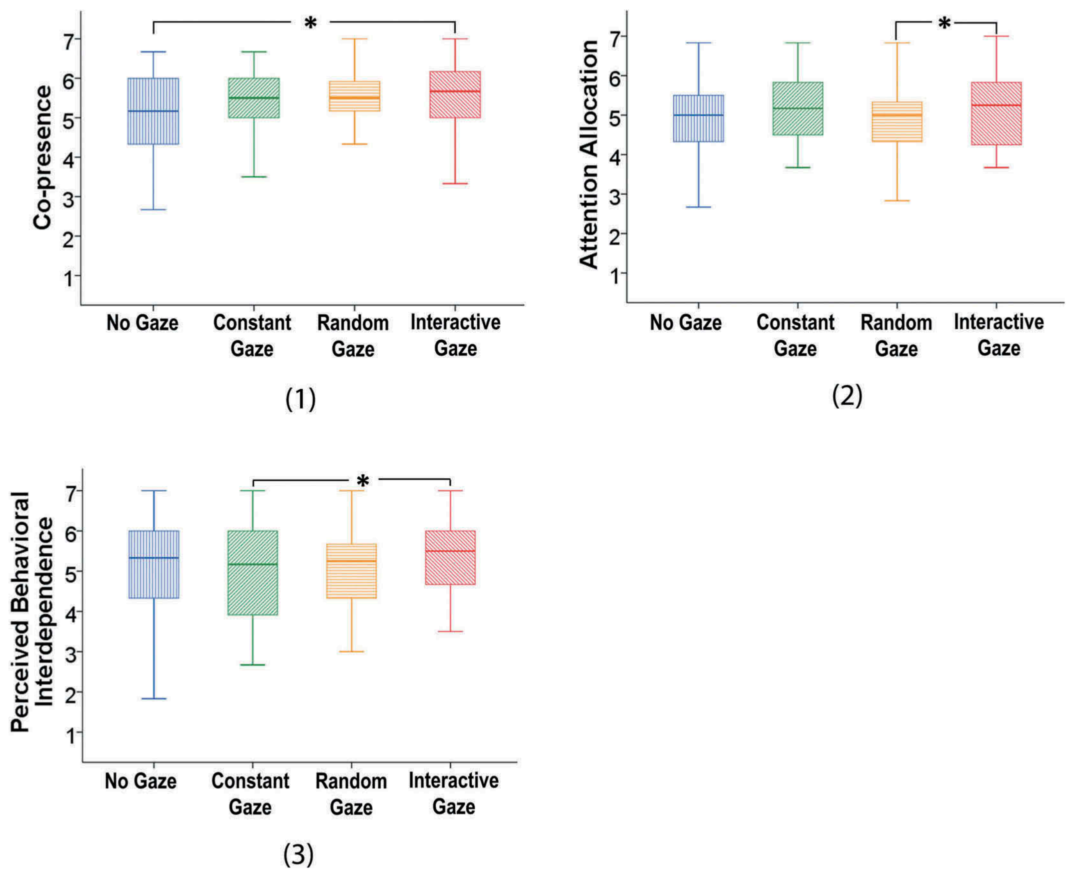


Figure 8. Boxplot of the main effect of four gaze conditions on co-presence, attentional allocation, and perceived behavioral interdependence. Significant group difference; * $p < .05$, ** $p < .01$.

using four gaze conditions (No Gaze, Constant Gaze, Random Gaze, Interactive Gaze) as the within-subjects factor, and the participant roles (blind participants, sighted participants) as the between-subjects factor.

5.1.2.1. Co-presence. A non-significant main effect was observed among four gaze conditions [F(3, 54) = 1.558, *p* = .210]. Although not significant, the sighted participants felt higher co-present in the Interactive Gaze condition (M = 5.57, SD = .82) than the No Gaze condition (M = 5.20, SD = .87), the Constant Gaze condition (M = 5.32, SD = .74), and the Random Gaze condition (M = 5.24, SD = .55). The predicted interaction between gaze conditions and the participant roles was not significant [F(3, 54) = .721, *p* = .544].

5.1.2.2. Attentional allocation. A non-significant main effect was observed among four gaze conditions [F(3, 54) = 1.103, *p* = .356]. Although not significant, the sighted participants experienced higher attentional allocation in the Interactive Gaze condition (M = 5.13, SD = 1.17) than the No Gaze condition (M = 4.70, SD = .78), and the Random Gaze condition (M = 4.63, SD = 1.16). The predicted interaction between gaze conditions and participant roles was also not significant [F(3, 54) = 1.009, *p* = .396].

5.1.2.3. Perceived Message Understanding (PMU). A non-significant main effect was observed among four gaze conditions [F(3, 54) = .590, *p* = .624]. Although not significant, the sighted participants experienced higher PMU in the Interactive Gaze condition (M = 5.44, SD = .98) than in the No Gaze condition (M = 5.10, SD = .88), the Constant Gaze condition (M = 5.37, SD = .78), and the Random Gaze condition (M = 5.18, SD = .83). The predicted interaction between gaze conditions and participant roles was also not significant [F(3, 54) = 1.456, *p* = .237].

5.1.2.4. Perceived Affective Understanding (PAU). A non-significant main effect was observed among four gaze conditions [F(3, 54) = .641, *p* = .592]. Although not significant, the sighted participants experienced higher PAU in the Interactive Gaze condition (M = 5.10, SD = 1.25) than in the No Gaze condition (M = 4.85, SD = 1.05), and the Random Gaze condition (M = 5.00, SD = 1.05). The predicted interaction between gaze conditions and participant roles was also not significant [F(3, 54) = .417, *p* = .741].

5.1.2.5. Perceived Emotional Interdependence (PEI). A non-significant main effect was observed among four gaze conditions [F(3, 54) = .263, *p* = .852]. The predicted interaction between gaze conditions and participant roles was also not significant [F(3, 54) = 1.186, *p* = .324].

5.1.2.6. Perceived Behavioral Interdependence (PBI). A non-significant main effect was observed among four gaze conditions [F(3, 54) = 1.016, *p* = .393]. Although not significant, the sighted

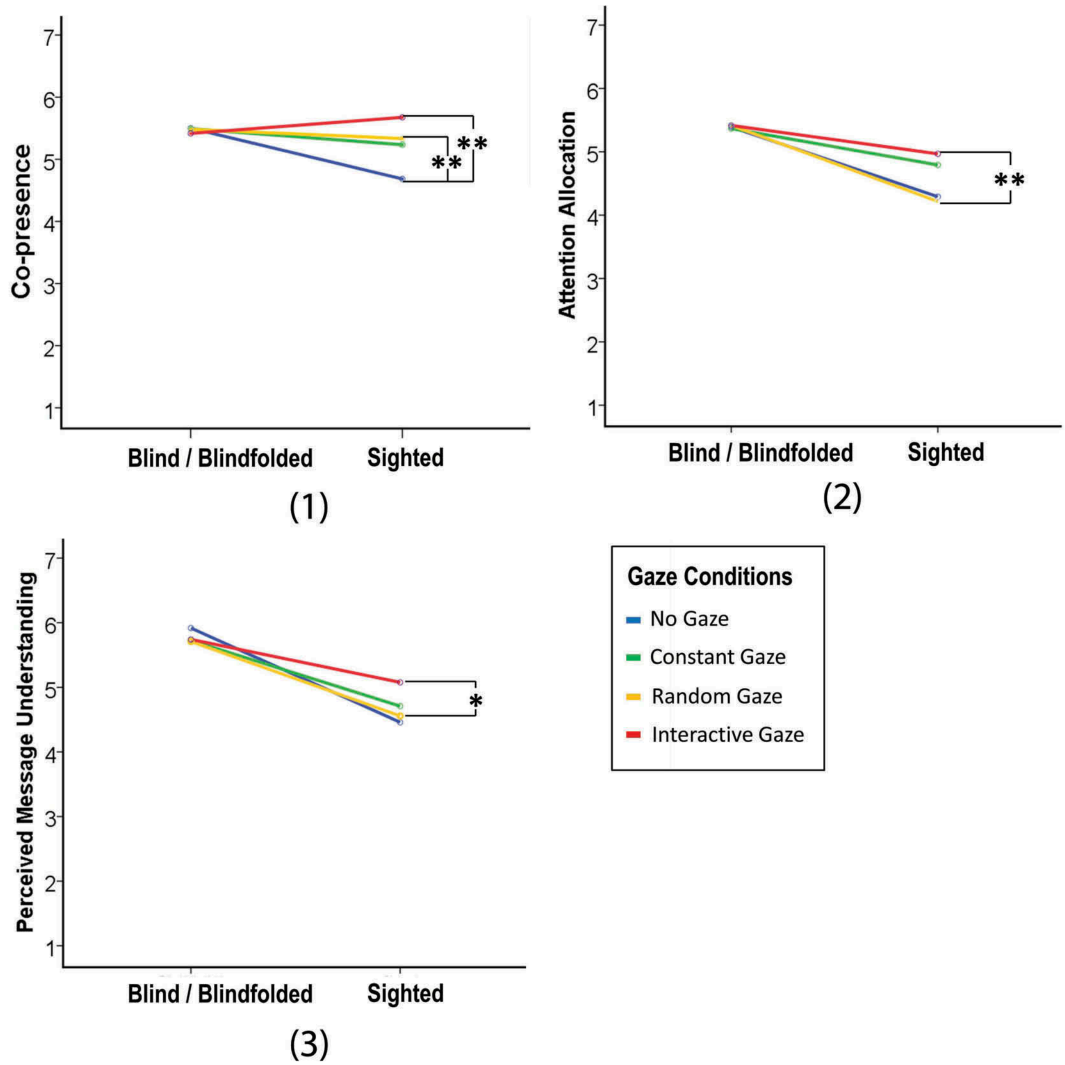


Figure 9. Interaction effects between four gaze conditions and participant roles on co-presence, attentional allocation, and perceived message understanding. Significant group difference; * $p < .05$, ** $p < .01$.

participants experienced higher PBI in the Interactive Gaze condition (M = 5.38, SD = 1.17) than in the No Gaze condition (M = 5.12, SD = .99), the Constant Gaze condition (M = 5.28, SD = 1.06), and the Random Gaze condition (M = 5.07, SD = .89). The predicted interaction between gaze conditions and participant roles was also not significant [F(3, 54) = .711, p = .549].

5.1.2.7. Closeness. A non-significant main effect was observed among four gaze conditions [F(3, 54) = .544, p = .655]. Although not significant, the sighted participants experienced higher closeness in the Interactive Gaze condition (M = 5.40, SD = 1.43) than the No Gaze condition (M = 5.30, SD = 1.57), the Constant Gaze condition (M = 5.20, SD = 1.55), and the Random Gaze condition (M = 4.90, SD = 1.20). The predicted interaction between gaze conditions and participant roles was also not significant [F(3, 54) = .181, p = .909].

5.1.2.8. Summary. Overall, we did not find any significant difference among four gaze conditions in the blind-sighted group. Although not significant, we observed that the sighted participants experienced higher co-presence, attentional allocation, PMU, PAU, PBI and closeness in the Interactive Gaze condition than the No Gaze and Random Gaze conditions. They also experienced higher co-presence, PMU, PBI and closeness in the Interactive Gaze condition than the Constant Gaze condition.

5.2. Qualitative results

We collected the participants' comments from the interview. Table 4 presents abbreviations used in the study. Eighty quotes from 20 sighted participants mention their perceptions toward four gaze conditions (Table 5).

5.2.1. No gaze

Two quotes mention the participants' positive attitudes toward the Social glasses. BFS-S8 stated, "*It seems to communicate with*

Table 4. Abbreviations used in qualitative results.

Abbreviations	Conversation Groups	Participant Roles
BS-S	Blind-sighted	Sighted
BFS-S	Blindfolded-sighted	Sighted

Table 5. The participants' perceptions toward four gaze conditions of the Social glasses.

Test conditions	Attitudes	Keywords and phrases	Number of quotes
No Gaze	Positive (frequency)	Relaxed (1); feel at ease (1)	2
	Negative (frequency)	Difficult to know the conversation partner's mood (9); easy to be distracted (6); a little scared (1); awkward (1); confused (1)	18
Constant Gaze	Positive (frequency)	Focused (2); magical (2); attractive (1); feel respected (1); vivid (1); realistic (1)	8
	Negative (frequency)	Be glassy-eyed and uncomfortable (6); no feelings (2); horrible (2); lifeless (1); disrespectful (1)	12
Random Gaze	Positive (frequency)	Amazing, trustable (1); attract the attention (1); feel very intimate (1); feel conversation partner's emotion (1)	4
	Negative (frequency)	Do not pay attention to me (5); easy to be distracted (5); impolite (3); uncomfortable (1), feel irritable (1); horrible (1)	16
Interactive Gaze	Positive (frequency)	Feel communicate with a sighted person (5); feel the conversation partner listen carefully (4); realistic (3); high-tech (1); magical (1); comfortable (1); natural (1); lovely (1)	17
	Negative (frequency)	Insincere (2); rigid (1)	3
Total			80

a person wearing the black glasses, and let me feel relaxed." Eighteen quotes mention the participants' negative attitudes toward the Social glasses in the No Gaze condition. An example quote is, "*I do not pay attention to the blind conversation partner, because I cannot see anything from the black screens of the glasses. It is difficult for me to know his mood*" (BS-S4).

5.2.2. Constant gaze

Eight quotes mention the positive factors of the Constant Gaze. BFS-S12 said, "*I feel my conversation partner is very earnest to listen to me, which encourages me to continue talking.*" Twelve quotes mention the negative factors of the Social glasses in the Constant Gaze condition. The participants reported that the constant gaze looked uncomfortable, horrible, and lifeless. They were more willing to look elsewhere than look at the Social glasses in conversations. BFS-S8 said, "*The eyes (displayed on the Social glasses) seem very monotonous and sometimes even horrible. My conversation partner always stares at me, which makes me feel uneasy. I want to take precautions against him.*"

5.2.3. Random gaze

Six quotes describe the positive factors of the Random Gaze. BFS-S10 said, "*It seems the conversation partner is thinking about the topic, and she is trustworthy.*" Fourteen quotes show the opposite ideas. The participants reported that the Random Gaze looked impolite and distracted their attention. They felt difficult to distinguish the real intention and feelings of the conversation partners. BFS-S20 said, "*I cannot feel the conversation partner concerns me in conversations. I always doubt that I speak something wrong or offend her in some aspects.*"

5.2.4. Interactive gaze

Most quotes (17 out of 20) mention that the Interaction Gaze could increase the participants' communication quality in conversations. BS-S2 said, "*I feel I am interacting with a sighted person in conversations […]*" The other example is, "*He carefully listens to me and think how to answer my questions*" (BFS-S12). Only three quotes mention the participants' negative attitudes toward the Interactive Gaze. BFS-S10 said, "*The eyes (displayed on the Social glasses) looks so rigid that I feel uncomfortable.*"

6. Discussion and conclusion

In this study, the hypothesis was well supported by the quantitative data. The quantitative results strengthened our confidence that Interactive Gaze was more effective than other three gaze conditions to improve the communication quality. Interactive Gaze positively affected the participants' co-presence, attentional allocation and perceived behavioral interdependence in conversations.

A significant interaction effect was also observed between gaze conditions and participant roles. The sighted participants experienced significantly higher attentional allocation and perceived message understanding in the Interactive Gaze condition than in the Random Gaze condition. The sighted participants also experienced significantly higher co-presence in the Interactive Gaze and Random Gaze conditions than in the No Gaze condition. The result was also supported by the qualitative data. Most sighted participants (17 out of 20) liked the Social glasses in the Interactive Gaze condition (Section 5.2). The sighted participants reported that Interactive Gaze looked more natural than the other three conditions. It portrays the blind conversation partner's attention as listening, increasing the overall communication quality in face-to-face conversations. This finding was consistent with one of the positive functions of gaze in face-to-face social interaction. Gaze often associates with conversation partners' attention and engagement, which has been well documented by many researchers (e.g., Argyle et al., 1994; Kendon, 1967; Kleinke, 1986; Rutter, Pennington, Dewey, & Swain, 1984). We also found that Constant Gaze was less favorable than Interactive Gaze. According to Argyle and Dean (1965), the relation between the gaze and how it is perceived is not linear. If someone likes a person more, she looks at that person more. But, if she looks for a greater proportion of the time than the norms for the situation permit, she will make the situation too intimate and may be seen as intrusive.

Also, we analyzed the data from the participants in the blind-sighted group for gaze conditions. Although there was not a statistically significant difference in the blind-sighted group, the sighted participants experienced higher co-presence, attentional allocation, perceived message understanding, perceived affective understanding, perceived behavioral interdependence and closeness in the Interactive Gaze condition than in other conditions. It indicates that Interactive Gaze still has a positive impact on the communication quality in the blind-sighted group, but this impact is smaller than in the blindfolded-sighted group. One of the possible reasons is the participants' verbal communication influence the communication quality. We used daily topics in the experiment, and all topics have been tested in a pilot study (Qiu, Rauterberg, & Hu, 2016). All topics were easy for the blindfolded and the sighted participants to start conversations. However, the topics with unfamiliar location information seemed difficult for the blind participants (e.g., museums, galleries and even their hometowns). Due to a loss of vision, they might not go out by themselves very often, and lack personal experience with these places. Compared with the blindfolded participants, it took more time for some blind participants to think and respond in conversations. Based on an observation from the experimental video, the researcher found that it caused some impatience from their sighted conversation partners.

Overall, this study has two major contributions: (1) an innovative wearable device was designed and developed that could help a blind person to establish the "eye contact" with the sighted conversation partner; (2) it provides evidence that Interactive Gaze has a positive impact on the communication quality in a dyadic-conversation scenario. To the best of our knowledge, this research is the first attempt at using the eye-tracking technology to simulate the natural gaze for blind people. Our experimental findings could be used to guide the development of gaze simulation systems. In this study, the Social glasses simulate the natural gaze for blind people. It helps establish eye-to-eye communication between blind and sighted people, enabling both sides to be more engaged in conversations.

Although the Social glasses system benefits blind people, it still has an inadequacy. Blind people cannot receive the feedback of gaze signals from sighted people in conversations. Griffin's Uncertainty Reduction theory (Griffin, 2006) suggested that, during face-to-face communication, blind people suffer from uncertainty about sighted people's attitudes, due to a lack of visual cues in social interactions, especially gaze and eye contact. They often experience communication breakdown in conversations, causing their low self-confidence and feelings of social isolation (Naraine & Lindsay, 2011) . In our future work, we will improve the Social glasses system to let blind people also feel gaze and "eye contact" in face-to-face communication. If the Social glasses could give the prompt of the gaze from the sighted, it could be used to help blind people to participate in a more effective social interaction. Many sensory substitution systems help improve the quality of blind people's lives by transferring visual signals into auditory signals (Mengucci, Watten, Hamilton-Fletcher, Obrist, & Ward, 2016; Tanveer, Anam, Yeasin, & Khan, 2013). However, using auditory feedback seems not suitable in a conversation scenario. It may increase the hearing load of blind people and make conversations annoying. Therefore, it will be very interesting to explore different modalities regarding the feedback for the "eye contact," such as vibrations, a sense of pressure, and even a change of temperature.

In addition to gaze and eye contact perception, we also consider making blind people actively influence the interactive gaze such as signaling turn-taking in conversations. Specifically, when a blind person ends talking, she can let the Social glasses display a "look at" eye gesture toward the sighted person, trying to signal the turn for that person.

According to Hagad, Legaspi, Numao, and Suarez (2011), dyadic (two-people) conversations are "ideal for studying social behaviors since not only are they easier to observe, it is also easier to develop a social connection between participants" (p.614). Therefore, in this study, we chose a dyadic-conversation scenario. In our future work, we will explore the effect of the simulated gaze in multi-party conversations that engage more than two participants. Sato and Takeuchi (2014) suggested that people take various positions in multi-party conversations, such as being actively involved or being a good listener. In such conversations, simulating the gaze will be more challenging than in dyadic conversations, but also more interesting as a next step. For instance, the revised prototype from Osawa, Goto, and Wang (2017) could be used for our future research to explore the simulated gaze in three-party conversations.

In our user experiment, all participants are from China, and they did not have any cultural differences. Thus, we do not explore how culture affects gaze behaviors. Many researchers have studied gaze behaviors between eastern and western cultures (Argyle, Henderson, Bond, Iizuka, & Contarello, 1986; Bond & Goodman, 1980; LaFrance & Mayo, 1976; Senju et al., 2013). Argyle et al. (1986) found that the rule "Should look the other person in the eye during conversation" was highly appreciated by English and Italian but not by Japanese and Hong Kong residents. Senju et al. (2013) investigated gaze behaviors of British and Japanese people when they looked at another person's face. The results supported the Western culture prefers the maintenance of eye contact in communication while the Eastern cultural requires flexible use of eye contact and gaze aversion. In our future work, we can try to implement the interactive gaze model that is aware of cultural distinctions.

In our current study, all the gaze durations of the Social glasses are predetermined according to the findings from psychology (Kendon, 1967) and the existing gaze model used in human-agent interaction (Bee et al., 2010). We want to explore alternative gaze simulation approaches. Our positive experimental findings encourage us to explore a more sophisticated simulation of "natural" gaze in future work (e.g., using a Markov model, or other statistic models, for gaze simulation).

Note

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

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Disclosure of potential conflicts of interest

We declare that we have no financial and personal relationships with other people or organizations that can inappropriately influence our work, there is no professional or other personal interest of any nature or kind in any product, service and/or company that could be construed as influencing the position presented in, or the review of, the manuscript entitled, "Social Glasses: Simulating Interactive Gaze for Visually Impaired People in Face-to-Face Communication".

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