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LONG PAPER

Understanding visually impaired people's experiences of social signal perception in face-to-face communication

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Abstract

Social signals (e.g., facial expression, gestures) are important in social interactions. Most of them are visual cues, which are hardly accessible for visually impaired people, causing difficulties in their daily living. In human–computer interaction (HCI), assistive systems for social interactions are getting increasing attention due to related technological advancements. Yet, there is still lack of a comprehensive and vivid understanding of visually impaired people's social signal perception to broadly identify their needs in face-to-face communication. To fill this gap, we conducted in-depth interviews to study the lived experiences of 20 visually impaired participants. We analyzed a rich set of qualitative empirical data based on a comprehensive taxonomy of social signals, using a standard qualitative content analysis method. Our results revealed a set of vivid examples and an overview of visually impaired people's lived experiences regarding social signals, including both their capabilities and limitations. As reported, the participants perceived social signals through their compensatory modalities such as hearing, touch, smell, or obstacle sense. However, their perception of social signals is generally with low resolution and limited by certain environmental factors (e.g., crowdedness, or noise level of the surrounding). Interestingly, sight was still importantly relied on by low-vision participants in social signal perception (e.g., rough postures and gestures). Besides, the participants experienced difficulties in sensing others' subtle emotional states which are often revealed by nuanced behaviors (e.g., a smile). Based on rich empirical findings, we propose a set of design implications to inform future-related HCI works aimed at supporting visually impaired users' social signal perception.

Keywords Face-to-face communication · Social signals · Visually impaired people · Accessible technology

1 Introduction

According to the World Health Organization (WHO) in 2017, it is estimated that 253 million people are visually impaired, in which 36 million are blind and 217 million have low vision [1]. Visually impaired people confront many challenges. One major challenge is that blind individuals have difficulties in perceiving certain social signals in face-to-face communication. Social signals can express a person's attitude toward social situations and interplay, most of which rely on a multiplicity of visual cues including eye behaviors, facial expressions, hand gestures, and body postures [2]. These visual cues are inaccessible for the blind and hardly accessible for low-vision people. The limitation of perceiving and expressing social signals can cause inconvenience for visually impaired people to participate in or follow up the conversations. Also, it may cause visually impaired people to suffer from impatience, or intolerance from some sighted conversation partners [3]. As a result, most visually impaired

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people choose to use passive strategies (e.g., only listening) in conversations [4]. According to Griffin's Uncertainty Reduction theory [5], during face-to-face communication, visually impaired people could suffer from uncertainty about sighted people's attitudes due to a lack of visual cues. They often experience communication breakdown in conversations, which could lead to their low self-confidence and feelings of social isolation [6]. Kemp et al. [7] also mentioned that blind people behaved differently in face-to-face communication from sighted people: They tend to be more introverted and submissive than sighted people during conversations or social activities.

As social beings, a fundamental need of humans is to establish and maintain social relationships [8]. Based on Abraham Maslow's hierarchy [9], once a person's basic needs (e.g., survival or security) are satisfied, he will strive to satisfy the need for a sense of belongings in communication and social activities. The majority of the assistive systems aim to provide access to facilities that can satisfy basic needs of visually impaired people, such as navigation devices [10–13], graphics access [14, 15], and Braille displays [16]. These assistive systems mainly focus on basic survival or security needs of visually impaired users. However, technology use cannot occur in a social vacuum [17]; identifying and supporting the social needs of this group of users are important as well. Therefore, nowadays, assistive systems for social interactions are getting increased attention due to the developments in multisensory research, computer vision, wearable technology, etc. Some studies implemented assistive systems for visually impaired people, which could help users identify conversation partners [18, 19] and their facial expressions [19]. Most of these studies are from a technology perspective, focusing on developing technology solutions to help visually impaired people in face-to-face communication. From a human-centered perspective, there still lacks vivid and contextual empirical knowledge about visually impaired people's real-life needs in face-to-face communication, which should include their limitations, as well as capabilities. Such empirical knowledge could help researchers or designers to empathize with this group of users, contextualize their design challenges and identify new design opportunities. Conversely, without a contextual understanding of visually impaired users' lived experiences, the support provided by technologies could sometimes bring burden to blind individuals. For example, certain assistive devices sometimes overly support users and unintentionally emphasize users' disabilities [17], which lead to a negative impact on visually impaired people on social occasions. In summary, it is therefore suggested that understanding visually impaired users' live experiences regarding social signals is a timely and relevant challenge, and such understanding should include both users' limitations and capabilities in their real-life context.

Consequently, the work presented in this paper has two research purposes:

(1) To investigate how visually impaired people experience their capabilities and limitations regarding perceiving social signals in real-life face-to-face communication;
(2) To inform the design of future human–computer interaction (HCI) systems to support visually impaired users' social signal perception. Given the explorative nature of our research aims, a methodology of in-depth qualitative empirical research has been chosen, to contribute vivid and contextual empirical knowledge about target users' lived experiences [20].

Our study involved 20 visually impaired participants experiencing total blindness to low vision and intended to cover a wide range of user experiences. We conducted in-depth online interviews with the participants, a commonly used approach in accessible studies [21], which may make visually impaired participants feel relaxed in communicating personal experiences and feelings, and more importantly, avoid their burden for traveling [4]. To gather participants' lived experiences regarding perceiving social signals, we collected rich qualitative data containing relevant examples from their real-life experiences. Based on the taxonomy of social signals by Vinciarelli et al. [2], we categorized these examples and generated an overview of our participants' experienced capabilities and limitations regarding social signals. This overview shows a different pattern than the existing taxonomy established for sighted people. For example, due to visual impairment, the participants often perceived social signals through the compensatory modalities (e.g., hearing, touch, smell, and the obstacle sense). However, such compensatory perception has many limitations. Facial expressions, gaze, and subtle gestures are in general not perceivable for the participants. They had trouble in discerning conversation partners' complex or subtle feelings. Different from what expected, sight was still commonly reported by various participants to be relied on to (roughly) perceive social signals (e.g., rough postures, gestures). Our rich contextual insights about the participants' lived experiences in face-to-face communication can provide an input for interaction design and the development of the accessible technology.

In this paper, we first address related work on visually impaired people's difficulties in face-to-face communication, relevant assistive systems as well as a taxonomy of social signals used for our analysis. Next, we describe the methodology and qualitative content analysis [22] used in the study and then present the major findings. Finally, we present design implications based on the results, which are to inform HCI design for assisting visually impaired people's social signal perception in face-to-face communication.

2 Related work

Related work presented in this section includes

(i) problems in face-to-face communication,
(ii) assistive systems to reinforce social signals, and
(iii) taxonomy of social signals.

2.1 Problems in face-to-face communication

Social signals—the interpersonal, nonverbal cues (e.g., hand gestures, facial expressions) that are often perceived through visual modality—play a vital role in everyday communication. According to [23], approximately 65% of dyadic conversation is nonverbal. It has been suggested by [24] that nearly 48% of the communication is through visual encoding of the face and body kinesis and posture [24], which visually impaired people may be unable to access or react to. For example, in face-to-face communication, high frequency of eye contact is generally linked with sincerity and friendliness, and low frequency of eye contact is often with insincerity and nervousness [25–27]. People who look at others during only 15% of the conversation time may be considered to be cold and lacking confidence [25, 26]. Much research has stressed the importance of social signals from a developmental perspective. In early social development, most parent–child interactions are established through the exchange of eye contact. Due to the lack of eye contact, the parents of blind infants may misread their children to be disinterested or unfriendly [28, 29]. Related to this, in the early stage, smiling behaviors of blind infants are similar to those of sighted infants; however, gradually, blind infants would smile less, since they cannot perceive returned smile from surrounding persons [28, 29]. From our daily experiences, during a group conversation, a question (or a topic) is often directed to a person through the gaze of the conversation partner(s), i.e., the conversation partner(s) look at that person to indicate that she should take the turn. In such situations, visually impaired people may find it difficult to know when to respond because they cannot perceive these gaze signals from others. As a result, they might be slow in responding to the conversation, or they might unintentionally take others' turn, which may cause unwanted embarrassment for them and thereby make them less confident and more passive in participating in a conversation. For the above reasons, in face-to-face conversation, behaviors of visually impaired people were reported to be different from those of sighted people [30]: Researchers observed fewer body gestures from visually impaired people; they turned toward conversation partners much less than sighted people; they felt less confident to share personal feelings. Over time, such situations can cause visually impaired people at a disadvantage, leaving them socially isolated [24].

2.2 Assistive systems to reinforce social signals

In HCI, an increasing number of studies have investigated how accessible technology can assist visually impaired people in social interactions. Some studies developed face recognition systems for visually impaired people, which help them identify their conversation partners. For example, Krishna et al. [31] presented a wearable device named iCare Interaction Assistant, to help blind users identify their sighted conversations partners in social interactions. Kramer et al. [32] also implemented a face recognition tool to help blind users identify people during group meetings, worn by a blind user helping to identify the faces of co-workers and colleagues from a database. Once a face is identified, the blind user can hear that person's name via a wireless earpiece. Neto et al. [18] used a Microsoft Kinect sensor as a wearable device to address blind people's difficulties of people recognition and localization.

Apart from using face recognition for the identification of conversation partners, some studies have presented assistive systems which can help blind people to identify their conversation partners' facial expressions. Instead of delivering information through the sense of hearing, such assistive systems often utilize the sense of touch to efficiently and unobtrusively convey social signals in conversation scenarios [33–36]. Krishna et al. [33] implemented a vibrotactile glove prototype to access facial expressions of the conversation partners. The prototype uses different vibration patterns to convey several types of facial expressions of a sighted conversation partner (i.e., happy, sad, surprise, neutral, angry, fear, and disgust). Similarly, Buimer et al. [34] presented a design solution to access facial expressions: A blind person wears a haptic belt with six vibration actuators around the waist. Each of them is assigned to a given emotion. The facial expressions are recognized by the software, converting from visual to vibration signals that the blind person can perceive. Moreover, Bala et al. [36] proposed the Haptic Face Display to convey facial movements for visually impaired people, where a vibrotactile chair is equipped with 48 vibration motors in direct contact with a person's back, aiming at providing the corresponding visual facial movements of the conversation partner.

In addition, a few studies also aimed at supporting blind people with other bodily cues such as head movements [37], or demographic information in a social occasion such as the number of people present and their age and gender distributions [38].

Although a variety of assistive systems have been implemented for visually impaired people in social interactions, HCI studies have rarely aimed for a comprehensive overview about the experienced capabilities and needs of visually impaired users regarding perceiving social signals in their everyday lives, in order to inform future design. To fill this gap, our study presents an in-depth qualitative analysis to comprehensively understand visually impaired users' lived experiences, based on an existing taxonomy framework of social signals.

2.3 Taxonomy of social signals

Commonly treated as a separate level of social interaction from verbal communication, social signals intuitively and tacitly convey nonverbal information between people, such as a feeling of being interested/bored, or friendly/hostile [39]. Social psychologists have been studying nonverbal behaviors for several decades [40, 41]. These studies have revealed the major role that nonverbal behaviors play in social interactions. For example, it is more accurate to judge the rapport between two people by using facial expressions than by using the verbal message exchanged [42]. Nonverbal behaviors seem honest to people, since they are more spontaneous and not as easy to fake as verbal responses [40]. Social signals express a person's attitudes toward social interactions, through a variety of nonverbal behaviors, including facial expressions, body postures and gestures, and vocal outbursts like laughter [2].

Vinciarelli et al. [2] conducted a survey of social signal processing (SSP), a new research domain that aims at enabling computers to understand social signals. They summarized relevant findings from social psychologists and established a taxonomy framework of social signals, in order to inform the development of computer systems that senses human social signals. In that context, our work is intended to inform the design of human–computer interfaces that support visually impaired users' perception of social signals. Therefore, we have based our systematic qualitative analysis on their taxonomy framework. However, to be noted, this taxonomy framework is originally based on how sighted people rely on social signals, and currently there is no taxonomy that has been established based on the lived experiences of visually impaired people. For this reason, another motivation of our work is to shed light on the possibly different experiences and needs of this special user group, in order to underlie future taxonomy works which specifically aimed at addressing how visually impaired users rely on social signals in everyday life.

In general, the taxonomy by Vinciarelli et al. includes *gestures and postures*, *face and eye behavior*, *vocal behavior*, *space and environment*, as well as *physical appearance*, which have been recognized as the most important categories of nonverbal cues in human judgements of social behaviors [2]. De facto, those categories of social signals have all been extensively discussed in other prior research. For example, many studies have explored how postures and gestures could communicate emotions [43, 44]. The first was the work of Darwin [45] that described body expressions associated with emotions in animals and humans. Gestures are in general used to regulate interactions, to communicate particular messages, to greet, etc. [2]. Postures include facing direction, walking, sitting, etc., regarded as the most reliable cues to show people's actual attitude toward social interactions [41]. Similarly, the category of face and eye behavior also concerns a large body of prior research. The face has the majority of the sensory apparatus, i.e., eyes, ears, mouth, and nose, enabling a person to see, hear, taste, and smell [2]. From the face, we can understand a person's intentions and affective state based on the facial expressions (e.g., fear, sadness, happiness) [46]. Gaze has five primary functions [47]: *providing information*, *regulating interaction*, *expressing intimacy*, *social control*, and *service task*. The category of vocal behaviors includes all spoken cues that surround the verbal message, which has five major components (i.e., voice quality, linguistic and non-linguistic vocalization, silences, and turn-taking patterns) [2]. For example, emotions such as anger or fear are often expressed with energy bursts in voice (shouts) [48, 49]. Factors subjected to space and the surrounding environment are also considered to be of the role of social signals in face-to-face communication. For instance, space or environment-related social signals could include how the conversation partners are interacting with the surrounding artifacts or spatial properties during the communication, or how the conversation partners are located in the space or environment [2, 49, 50]. Finally, the category of physical appearance can include both natural (e.g., height, body shape) and artificial characteristics (e.g., clothes, make up) of a person [2]. For example, a main social signal related to physical appearance is attractiveness, which produces a positive *hao* effect (i.e., "what is beautiful is good" [51]).

3 Methodology

3.1 Ethical approval

According to the Netherlands Code of Conduct for Scientific Practice (principle 1.2 on page 5), research on human subjects is permitted upon their freely given informed consent. All participants in this study 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. [52]).

3.2 Participants

We interviewed 20 participants over a three-month period. Participants were recruited until we had covered a wide range of visual impairment from mild to total blindness. The participants included eight women and twelve men, with a range of ages from 16 to 29 (M = 20.30, SD = 2.79). Ten participants were from Yang Zhou Special Education School in mainland China, and the other ten were from Hong Kong Blind Union. Most participants were high school, college, and university students. All participants in Hong Kong reported their vision conditions based on the official medical records. Some participants in mainland China were uncertain about their vision conditions, so a teacher in Yang Zhou Special Education School provided their vision conditions based on their disability certifications from China Disabled Persons' Federation (CDPF). WHO categorizes the visual impairment based on the visual acuity [53]. Based on the visual acuity, we converted the categories of visual impairment in mainland China and Hong Kong to the WHO standard. The twenty participants included one with severe visual impairment, and nineteen with blindness (from level 3 to 5). Fifteen out of twenty participants reported sight loss since birth. Eleven participants could perceive color and light, and other nine could not. The participants also reported as causes of their blindness hereditary reasons, premature birth, and sickness (cataracts and glaucoma).

3.3 Setup and procedure

Online interviews were conducted for data gathering. Tencent QQ and Skype were preinstalled in Yang Zhou Special Education School and Hong Kong Blind Union, respectively, and the online audio and video methods were offered to the participants. All participants chose the audio connection. To capture the data, we used QuickTime Player software to record the online interviews. A consent form was read out clearly by the interviewer to the participants. They were offered sufficient time to ask questions about the content of the consent for their understanding. They could then decide whether to give their consent by speaking clearly to the recorder. All the participants gave their consent for recording their interviews. During the interview, the interviewer orally explained all questions to the participants and each interview took approximately 1.5 h. Both English and Mandarin Chinese could be chosen by a participant in the conversation to ensure all participants had no language barriers and could understand each question well. Both English and Mandarin could be chosen by a participant in the conversation based on their preferences. Cantonese was not provided as an option since the interviewer is not proficient in Cantonese. However, all participants in Hong Kong are capable of oral communication in either English or Mandarin. Nine out of ten participants in Hong Kong chose Mandarin Chinese in interviews, while one participant chose English. All participants in mainland China chose Mandarin Chinese in interviews. The interview procedure was audio recorded and transcribed verbatim. In order to secure sensitive personal information, each participant was assigned to a unique ID number. The participants' last names were not used in the transcripts of the recording. Audio recordings were erased as soon as the study was completed. Each participant was compensated with 100 CNY in Yang Zhou Special Education School or 120 HKD in Hong Kong Blind Union at the end of the study. The interview protocol included two parts:

- *Background* We began by asking participants about their vision conditions and other demographic information;
- *Social signals in face-to-face communication* We first explained the meaning of social signals to the participants and then asked them about specific topics, such as the following.

1. Which nonverbal signal do you perceive in face-to-face communication (e.g., gestures, postures, face behaviors, facial expressions, gaze) and how do you perceive such nonverbal signals?
2. Can you perceive the moods of sighted conversation partners (e.g., happiness, anger, or impatience) by nonverbal signals in face-to-face communication? If yes, how do you perceive?
3. Which problems do you meet in face-to-face communication due to a lack of visual cues?

Since this study is to a large extent explorative, we not only asked questions directly but also asked follow-up questions based on the participants' previous answers and spontaneous comments.

3.4 Data analysis

The 20 interviews were transcribed verbatim. We analyzed the whole set of the data using a standard analysis method named qualitative content analysis [22]. Qualitative content analysis originated from Scandinavia in the eighteenth century [54] and is increasingly used recently by researchers from different disciplines such as health or clinical research [55], or HCI design research [56, 57]. The aim of using qualitative content analysis is to comprehensively interpret the content of textual data set though systematic coding and categorizing. Rather than standing for a single approach, qualitative content analysis contains three variants: *conventional*, *directed*, and *summative content analysis*, which have been, respectively, introduced by [22]. Both conventional and directed qualitative content analyses aim to establish an in-depth understanding regarding the content and contextual meanings of quotes that are selected from the data set, while summative content analysis is often intended to generate an overview of the textual data set by identifying the patterns of how and how often certain keywords are used in the data set. However, there is a major difference between conventional and directed qualitative content analyses: Directed qualitative content analysis is opted for only when the researchers already have an existing theory, model, framework, or taxonomy for selecting and classifying the quotes, and conventional qualitative content analysis is opted for otherwise.

Given the fact that our aim is to establish an in-depth understanding about our participants' lived experiences rather than identifying the patterns of keywords, and the fact that our analysis will be mainly based on an existing taxonomy of social signal by Vinciarelli et al. [2], our study has utilized the process of directed qualitative content analysis, which has been described in [22]. Nonetheless, we will still address the process of our data analysis, which consisted of two steps: *quote selection* and *collaborative coding*.

Quote selection According to our research aim, quotes were selected from the interview transcript based on the following scheme:

(1) Each selected quote should describe how the participant perceives a certain social signal, or how the participant lacks a social signal in their daily communication in face-to-face occasions;
(2) Each selected quote should only represent a single described situation regarding a single social signal;
(3) If multiple quotes are representing the same described situation, only one of them will be selected. This scheme guarantees that the selected quotes well reflect relevant information concerning our research aims and that they are mutually exclusive without semantically repeating each other.

Collaborative coding A total of 248 quotes were selected based on the mentioned scheme and were subsequently processed by two coders (SQ & PA) in a collaborative coding session carried out over the course of 2 months. The coding session uses the following process:

(1) Each coder reads all the quotes and made annotations/notes to establish their own understandings about the data, based on which they also gave initial labels to the quotes, according to the existing framework of social signals [2];
(2) The coders explained to and argued with each other about their own initial coding results and tried to reach an agreement in a discussion session. During a month, this discussion session was repeated regularly so that the coders could iteratively reach an agreement on a finalized categorization of all the quotes.

4 Findings

We aim at understanding the participants' capabilities, limitations, and needs regarding perceiving social signals based on their lived experiences in daily lives. In this study, we collected a total of 248 quotes (see Table 1).

Social signals In total, 151 quotes describe the participants' capabilities of perceiving social signals in face-to-face communication (Fig. 1), including posture and gesture (100 quotes), vocal behavior (30 quotes), space and environment (17 quotes), physical appearance (1 quote), and others (2 quotes). Another 97 quotes show the

Table 1 Categorization of the participants reported capabilities and limitations regarding social signals and perceptive modalities

M	S						
	Posture and gesture {N)	Face and eye behavior (N)	Vocal behavior (N)	Space and environment (N)	Physical appearance (N)	Others(N)	Total (N)
Capabilities							
Hearing	35	0	30	7	0	0	72
Sight	31	0	0	1	1	1	34
Touch	28	0	0	3	0	0	31
Obstacle sense	3	0	0	4	0	0	7
Smell	0	0	0	0	0	1	1
Others	3	1	0	2	0	0	6
Total	100	1	30	17	1	2	151
Limitations	44	41	0	7	2	3	97
Total	144	42	30	24	3	5	248

M Modalities; *S* Social signals; *N* Number of quotes

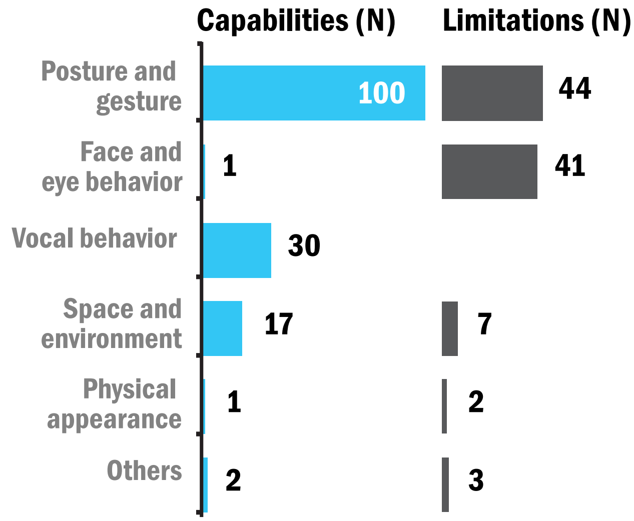

Fig. 1 Capabilities and limitations of the participants' social signal perception in face-to-face communication. (N) stands for the number of quotes

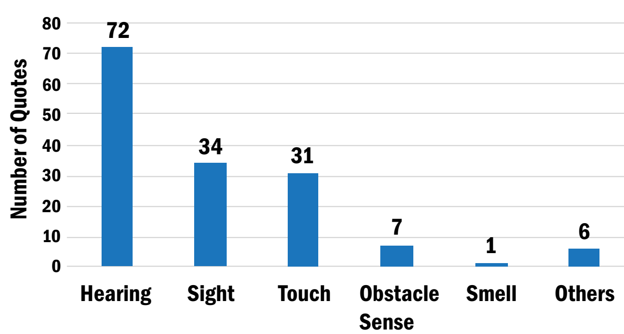

Fig. 2 Number of quotes for each modality that the participants could perceive social signals in face-to-face communication

participants' limitations (Fig. 1), including posture and gesture (44 quotes), face and eye behavior (41 quotes), space and environment (7 quotes), physical appearance (2 quotes), and others (3 quotes).

Modalities The participants could perceive social signals by five major modalities: hearing (72 quotes), sight (34 quotes), touch (31 quotes), obstacle sense (7 quotes), smell (1 quote), and others (6 quotes) (Fig. 2).

4.1 Posture and gesture

The category *posture and gesture* includes five sub-categories: *head pose*, *body touch*, *postures in the fixed position*, *postures in walking*, and *hand and arm gestures*.

4.1.1 Head pose

A total of 35 quotes provide information about participants' perception of facial orientation in face-to-face communication, in which 11 describe their experienced limitations and 24 quotes describe their capabilities regarding perceiving this social signal. As experienced by the participants, relying on facial orientation, they may get a clue on whether their conversation partners are concentrated on the current conversation: "*If a person turns his face away, it means she is not focused on what I am saying, or, she doesn't want to listen to me*" (P5). Alternatively, they may infer the emotional state of their conversation partners: "*If (the person is) not facing to you while talking, he might be upset, I guess"* (P3). Furthermore, knowing the conversation partner is facing to them also enables the participants to respond properly through their facial orientation: "*If I know [the person's] facial orientation, I will deliberately turn [my head]"* (P16).

Capabilities The most frequently mentioned way (15 quotes from 14 participants) for the participants to roughly sense their conversation partners' facial orientation is through hearing, namely listening to their conversation partners' voice, e.g., P18: "*[You] can hear whether [other people] are facing to you or not when [they are] speaking*". Some of the participants (P6, P11, P14) also reported that in this way, they could sense the facial orientation of multiple people: "*around two to three"* (P14), or "*up to three to four"* (P11), in the situation "*if the surrounding is not noisy"* (P14). Seven quotes from five participants report that they can also roughly sense others' facial orientation through sight, but only if "*the distance is close enough"* (P19), or "*there aren't many people around"* (P4).

Limitations The most mentioned (P5, P8, P17, P18) limitation regarding perceiving this social signal is that they can hardly determine their conversation partners' facial orientation if their conversation partners are not talking: "*I can't tell [his facial orientation] when he is not talking"* (P8). Also, as pinpointed by P2, P16, such sensing through hearing is not very accurate. Another limitation mentioned by the participants is that if the surrounding is very noisy or crowded, sensing others' facial orientation becomes even more challenging: "*If many people are sitting around me […], I cannot decide if [a person] is speaking to me"* (P4). Additionally, P5 also mentioned an example that he missed head moves like nodding or head shaking in a group conversation: "*Some people nodded, and some shook their heads, I couldn't see, and I thought they were thinking, then I asked them to hurry up*".

Implications In summary, the participants experienced that they could roughly sense their conversation partners' facial orientation mostly through hearing their conversation partners' voice. However, their experienced limitations suggest that technology could help them better perceive this social signal, especially when their conversation partners are not talking, or when the surrounding is noisy or crowded. This may support the visually impaired users to better know whether their conversation partners are attending to them (or others in the occasion), or engaged in the current conversation with them. Also, knowing others are facing them can help them respond. Additionally, technology can also support them to perceive the nodding and head shaking of their conversation partners.

4.1.2 Body touch

Twenty six quotes from the participants provide information regarding perceiving the social signal of body touch. Of them, two mention the limitation of relying on body touch as a social signal.

Capabilities As experienced by the participants, body touch could be used to communicate positive emotions through their conversation partners: "*At a happy moment, a good friend may place his arm on your shoulder while talking"* (P13). There are eight quotes that describe an example of how body touch (e.g., handshaking, hugging, shoulder patting) is used to communicate emotional feelings to the participants from their conversation partners; seven of them are about positive emotions such as happiness (P4), hospitality (P8), or encouraging and supporting (P6, P7). Seemingly, regarding emotions, body touch is mostly used to convey positive emotions to the participants.

According to the participants' experiences, body touch could also be used to convey intentions to them: "*[when someone is talking] If he nudges me, I would know that he is actually talking to me"* (P3) "*If she holds my hand, I would know that she is guiding me to place it [an object] in a certain location*" (P19), "*For example, on a public occasion, I was talking. A sighted person [a friend] touched my hand, meaning I should stop talking. But this [hand touching] has different meanings in different situations*".

Limitations Body touch is a very useful social signal for the participants since touch, in general, is an important sense for them: "*To us, the sense of touch is sometimes rather important"* (P9). However, the limitation of receiving body touch as a social signal has been explicitly mentioned. As P13 indicated, "*Blind students normally don't like body contact, unless [they are] with very good friends*" and "*I rarely touch others. And others rarely touch me. [Body contact] feels a bit invasive to my privacy [personal space]*". The examples gathered from other participants also suggest that they received body touch as a social signal mostly from people they are quite familiar with.

Implications Body touch plays an important role as a social signal for the participants to sense (mostly positive) emotions or intentions from their conversation partners. However, body touch is limited in the sense that it is mostly used between the participants and people they are familiar with. Technology may support the visually impaired users to receive actuator-mediated "body touch" from their conversation partners without having actual body contact or requiring intimate proximity. Thus, they may feel more comfortable to accept this social signal from people they are less familiar with in face-to-face communication.

4.1.3 Postures in the fixed position

In 32 quotes, the participants talked about their experiences regarding perceiving their conversation partners' postures with fixed positions: 22 of the quotes describe their capabilities of perceiving this social signal, while 10 of them describe their limitations.

Capabilities Thirteen quotes from eight participants mention that they can roughly see their conversation partners' postures with fixed positions. For example, P10 can decide whether the conversation partner is leaning by seeing if his/her figure becomes "*shorter*". Other general postures like "*crouching"* (P5) or "*standing still"* (P10) were also reported to be seen. Eight quotes from six participants indicate that they can roughly infer their conversation partners' position through hearing. For example, P14 mentioned that he could determine whether his conversation partner is leaning forward or backward by listening to his conversation partners' voice. Similarly, he can also hear whether his conversation partner is crouching. As P19 reported, by knowing the conversation partners' posture, he can feel the conversation partners' emotional state: "*When* [*the person's*] *body moves dramatically* […] *you could feel he is very emotional, angry* […]". Additionally, P16 reported that although he cannot fully explain, he can sometimes identify a person through certain features of his/her posture.

Limitations As the participants suggested, their sensing of conversation partners' body posture (in fixed positions) is limited to some large or drastic postures (P4, P9) such as leaning, standing still, crouching, or shaking (P13). And the corresponding information they can get is also rough. Like P13 reported, "*If* [*my conversation partner is*] *not speaking, I'm not sure whether* [*his/her*] *body shaking is because of being happy or upset*". By missing the details in the perceived postures, it could be difficult for the participants to receive relatively subtle information in social communication. For example, P17 described an example of practicing stand-up comedy with another person. He felt that "*Some of* [*the person's*] *postures and humor I could sense, but some of them I couldn't sense* [… *I*] *missed certain bodily aspects* […]". Moreover, their sensing of posture is also limited to the environment. For example, as experienced by P13, it may become rather challenging to perceive the conversation partner's posture "*If there are many people, and I'm focused on speaking*".

Implications In sum, the participants could roughly sense some extended or drastic postures in the fixed position (e.g., leaning, crouching, and shaking) of their conversation partners during face-to-face communication. Moreover, they may sense the identity or emotion of their conversation partners through their postures. However, their sensing lacks detailed or subtle information and is limited to the environment. Technology may help them perceive the conversation partners' posture more accurately, especially when the surrounding is crowded or when their conversation partners are not talking. Also, technology may help them better perceive the details in postures to enrich this social signal for them.

4.1.4 Postures in walking

Eleven quotes from the participants are about perceiving the social signal of postures in walking. Ten of them describe their capabilities regarding perceiving this social signal.

Capabilities Eight quotes from five participants show that they mostly perceive this social signal through hearing the footsteps of their conversation partners. As reported by P16, through hearing the walking behavior of another person, he may be able to identify that person. "*I can identify different people based on their footsteps.* (P16)". P12 also experienced that the pace of walking might be a clue for a person's current state: "*If the person wants you for some [urgent] business,* […] *the footsteps will sound more hurried than usual*". Interestingly, six out of eleven quotes (from P9, P10, P12, P16) suggest that the participants may also sense their conversation partners' emotional state from their walking behaviors. For example, P10 indicated that a person is probably happy "*If the footsteps sound slow and relaxed*". P16 experienced that "*The atmosphere feels different if* [*a person is*] *walking towards you angrily*".

Limitations P9 mentioned a limitation regarding perceiving walking posture of others: When he is also walking, he may bump into someone else unintentionally.

Implications To summarize, the participants can perceive walking postures by hearing their conversation partners' footsteps in daily communication. Relying on this social signal, they may be able to know the identity of a person or infer the current activities/emotions of the person. However, when they are also walking, they may need more accurate information about this social signal to avoid interfering with other people in walking.

4.1.5 Hand and arm gestures

Forty quotes from the interviews encompass the participants' perception of their conversation partners' hand and arm gestures in face-to-face communication. Among them, 20 quotes mention their capabilities of perceiving this social cue while 20 of them mentioning their limitations.

Capabilities Nine quotes from seven participants reported that they could roughly see the certain hand and arm gestures if the gestures are performed through the arm or the whole hand (e.g., pointing to a direction), or, in an extended/drastic motion (e.g., waving, flapping). Four quotes (P1, P10, P11, P14) show examples that they could also hear certain extended/drastic gestures through the sounds of airflow, or clothes. Three quotes indicate that they could also sense the airflow caused by gestures through tactile feeling. Interestingly, three quotes (P10, P12, P17) inferred that they could sometimes roughly sense a close-by gesture through obstacle sense, e.g., P13: "*If someone waves a hand before my face, I can sense it. [It is] not the sound of airflow, [but] a feeling of being blocked. Not the sense of light neither. I couldn't tell exactly, probably that is the obstacle sense*".

Limitations Twenty quotes mention the participants' limitations of perceiving gestures. They especially experienced that they cannot perceive certain subtle gestures (e.g., scratching head, P5) or gestures performed only through fingers at all. They indeed experienced certain inconveniences caused by missing the hand or arm gestures in face-to-face communication. For example, "*Without gestures, on certain occasions that things cannot be said, others cannot convey information to me"* (P18). The inconvenience mentioned most (in five quotes) is that the participants cannot sense their conversation partners' fingers pointing to certain directions. For example "*In Hong Kong, some people tend to point to somewhere and ask me to go there, but I can never understand that"* (P20), or "*When playing face-to-face games… some people pointed to another person, and I couldn't see which one they were pointing"* (P15).

Implications In sum, the participants experienced that they can sometimes roughly sense certain extended/drastic gestures performed by the arm or whole hand; however, they were not able to sense relatively subtle gestures performed by fingers. The most frequently mentioned inconvenience of missing the gestures in face-to-face communication is that they cannot sense the pointing of their conversation partners' fingers.

4.2 Face and eye behavior

The category *face and eye behavior* includes two sub-categories: *facial expressions*, as well as *gaze* and *eye contact*.

4.2.1 Facial expressions

Twenty-one quotes from the interviews describe the participants' perception of conversation partners' facial expressions. Among them, only one quote mentions the capability of her own facial expressions while 20 of them mention the limitations.

Capabilities Participant P9 reported that generally, she could explicitly know facial expressions of her own by perceiving facial muscle movements when she was smiling or expressing anger.

Limitations Twenty quotes mention the participants' limitation of sensing facial expressions. P3 often lost interest in discussions. One possibility is that conversation partners' facial expressions could not impress him when they were discussing something excited. The majority of participants faced many difficulties in discerning conversation partners' subtle or complex feelings because they could not sense their conversation partners' facial expressions. Examples include "*In face-to-face communication, I cannot know my conversation partners' mood if they do not speak out*" (P7) or "*Sometimes my friend imitates a very funny expression in our conversation, but I cannot sense it and naturally do not know why other people laugh*"(P4), and"*I am not sensitive to conversation partner's positive feelings unless he is laughing* [...]" (P19). Misunderstandings sometimes occurred in face-to-face communication caused by missing facial expressions, e.g., "*My classmate said 'yes' and agreed with me, but actually he was unpleased and disagreed with me. I cannot feel his unhappiness from the voice tone, which sounds as usual*"(P5).

Implications Overall, all participants could not perceive conversation partners' facial expressions in face-to-face communication. Since facial expressions typically associate with emotions in evolutionary history [58], participants met difficulties in distinguishing conversation partners' emotions, sometimes even causing misunderstandings in face-to-face communication.

4.2.2 Gaze and eye contact

Twenty-one quotes from the interviews describe the participants' perception of their conversation partners' eye behaviors in face-to-face communications. All of them mention the participants' limitations.

Limitations Twenty-one quotes mention the participants' limitation of sensing eye behavior. Because of missing eye behaviors, participants were unable to discover who or what conversation partners were looking at, which might impede the participants' performance in face-to-face communication. For example "*Many sighted people use eye contact to communicate with each other. A certain gaze may signal the end of speaking. I cannot feel the sighted conversation partners' gaze, which impedes me to join their discussions*" (P19), or "*In public space, the sighted sometimes use the gaze to stop talking that I cannot perceive and respond* [...]" (P12). P1 also stressed that due to a lack of the eye contact, he was unable to catch up the speed of discussions with sighted conversation partners. One possibility is the gaze which is an important sign for taking turns in conversations [59]. The participants experienced difficulties in handling conversation turns when missing the eye contact. Interestingly, although P2 did not realize the importance of gaze in face-to-face communication, P11 and P12 tended to exaggerate the gaze function. They gained an understanding of gaze by reading novels and other literary works, especially some romance novels describing the eye contact between lovers. Such romance novels often use figures of speech to vividly depict the gaze or eye contact, exaggerating their imagination toward the gaze function, e.g., "[...]*looking at a person's eyes can immediately know he is kind-hearted or not*[...]" (P11). Actually, even for the sighted people, it is still difficult for them to determine a person's inner character at first sight.

Implications In sum, all participants could not perceive any conversation partners' eye behaviors in face-to-face communication. They understood gaze behavior from their own life experiences, mostly based on the communicative problems they met (e.g., difficulties in handling conversation turns). They seldom realized gaze behavior could link with many expressions of the feelings (e.g., expressing intimacy, providing liking, and attraction) [47]. Some participants understood gaze by reading romance novels, which exaggerated their imagination toward the gaze function. They still had an indirect and fuzzy understanding regarding the eye behaviors.

4.3 Vocal behavior

Thirty quotes from the interviews encompass the participants' perception of their conversation partners' vocal behaviors in face-to-face communications. All of them mention their capabilities of perceiving this social cue.

Capabilities Twenty-three quotes mention that participants could perceive the conversation partners' emotion from their vocal behaviors (e.g., tone, tempo, energy in the voice). Examples include: "*I perceive conversation partners' emotion primarily relying on their spoken language and tone in the voice. Otherwise, I hardly know their emotions*" (P3); "*People use a different tone of voice to convey different emotions. I can perceive their emotions only by their tone in conversations*" (P20). Three quotes (P2, P7, P16) describe participants' perception of intense feelings (e.g., conversation partners' anger and happiness) based on their vocal behavior. However, participants seemed to have a limitation of perceiving conversation partners' subtle feelings through their voice in face-to-face communication, at least they never reported such experiences in interviews: "*I can only distinguish the conversation partner is happy or angry by hearing his tone in the voice. I cannot distinguish other emotions by the tone*" (P16); "*I can know a conversation partner's facial expressions by the sound (e.g., crying or laughing)*" (P7). Nine quotes from eight participants mention their experiences of perceiving conversation partners' negative feelings by their vocal behaviors in face-to-face communication, including a sigh, a harsh and impatient tone, awkward silence, as well as shortness of breath. For example, "*I can perceive a conversation partner's unhappiness from his tone and silence*" (P9), "*If the conversation partner becomes angry, she starts to be short of breath"* (P12). Four quotes from three participants (P3, P5, P17) mention that they perceived positive feelings by conversation partners' vocal behaviors, mostly relying on laughing. Only one quote stated that she could feel the conversation partner's kindness when he spoke in a very soft tone (P17).

Implications In sum, participants could perceive a person's emotions by vocal behaviors: If the voice is soft and gentle, participants tend to believe the conversation partner is pleasant; if the conversation partner speaks rudely and loudly, they probably think s/he is angry. The participants could explicitly distinguish conversation partners' intense feelings in conversations. However, they were not sensitive to understand subtle feelings from conversation partners' vocal behaviors. They seemed to perceive more negative rather than positive feelings by conversation partners' voice.

4.4 Space and environment

Twenty four quotes describe how the participants perceive the social signals belonging to space and environment, among which 17 quotes are about their capabilities and seven about their limitations.

Capabilities Seven quotes from five participants mention that they sense this social signal through hearing. For example, as P4, P15, P17 reported, they can hear how their conversation partners interacted with the environment through the sounds of artifacts being moved. Other quotes mention examples that the participants also sensed this social signal through touch (three quotes) or obstacle sense (four quotes). For example, P20 reported that while having a conversation, "*I like to touch those things that I can't see"* and this may help him better understand about the conversation. Another example from P12′s experience is about obstacle sense: He is sometimes able to feel certain objects approaching in front of him when *"*[*my*] *attention is focused*," and "*the surrounding is very quiet*". The participants reported that by sensing this social signal, they could know not only what their conversation partners are doing with the surroundings, but also what their emotional state is (P4, P9, P15, P17). For example, P15 reported that he could tell that a person may be unhappy if s/he closed the door loudly. Similarly, P4 experienced that if a person "*puts something down very hard, then you know he is not happy*".

Implications In sum, the participants mentioned that they could sometimes roughly perceive the social signal regarding space and environment through hearing, touch, or obstacle sense. This social signal can help them to know how their conversation partners interact with spatial and environmental factors during the conversation and how their conversation partners' emotional state may be. However, they may need richer information regarding this social signal to help them better participate in the conversation which involves interaction with artifacts. They may also need to be informed of the changes in the environment or things made by others to reduce inconvenience in face-to-face occasions.

4.5 Physical appearance

The social signal of physical appearance was rarely mentioned by the participants. Three quotes report the participants' experiences regarding perceiving it. One quote mentions a participant's (P9) capability of perceiving this social signal: "*I can roughly see the shape of people, and the color of their clothes*". Two quotes mention the participants' (P7, P10) experienced limitations regarding missing this social signal in interpersonal communication. As P10 experienced, missing this social signal disappointed her because she could not recognize the familiar people before the conversation. As she put it, "*If it is a familiar person, it would be nice that I know who the person is so that I can greet the person beforehand. That can show my warmth*". Therefore, the designed technology could help the visually impaired users to recognize the physical appearance of an adjacent person before the conversation.

5 Discussion

Our research aimed to contribute vivid and contextual empirical knowledge regarding visually impaired users' perception of social signals in their real-life occasions. In order to do so, we have gathered rich qualitative data based on our participants' lived experiences. We are motivated by the fact that although supporting the social signal perception of visually impaired users has become a timely topic, there still lacks comprehensive understanding about their real-life needs in face-to-face communications. Our findings are intended to help researchers or designers to empathize with this group of users, contextualize their design challenges, and identify new design opportunities.

The present research has extensively investigated participants' lived experiences regarding their limitations, as well as their capabilities. We argue that to properly frame this group of users' needs, understanding their capabilities is just as important as understanding their limitations. This is because sometimes, assistive technologies may underestimate users' ability and therefore overly support users or unintentionally emphasize users' disabilities [17], leading to a negative impact on visually impaired people in social occasions. The support intended by technologies may thereby unintentionally become burdensome in practice. For this reason, we have asked our participants to freely share their lived experiences of perceiving social signals regarding both their capabilities and limitations.

As indicated in the data obtained, in general, the participants shared more experiences of their capabilities than limitations: Among the 247 quotes, 150 quotes are about their capabilities and 97 about their limitations. Our research has been based on the existing taxonomy of social signals established for sighted people, since there is no taxonomy or framework of social signals specifically for visually impaired users. Nonetheless, the overview of our participants' experiences of social signals indicates a difference from the existing taxonomy established for sighted people: 1) Facial expression and gaze are not perceivable; 2) small posture and gesture are difficult to receive; 3) physical appearance is rarely talked. However, according to the reported capabilities, the participants could perceive social signals through their compensatory modalities (e.g., hearing, touch, smell, and the obstacle sense). Such compensatory mechanism is also reported by some neurophysiological research, which has found that visually impaired people's other sensory modalities (such as hearing and touch) could be enhanced due to loss of visual input [60]. The above findings therefore suggest that although visually impaired users have certain limitations in terms of social signal perception (e.g., low resolution of their received social signals, or limitations of environmental factors), they have also developed their own way of perceiving social signals, which reveals a different pattern than that of sighted people and which ought to be better and more systematically understood by future studies. As a result, it is deemed meaningful for future research to establish the taxonomy of social signals which is specifically for visually impaired people.

Interestingly, as also addressed in our findings, sight was still reported to be relied on by many low-vision participants in perceiving social signals such as rough postures and gestures. Moreover, social signals (e.g., smile, nod) often associate with emotional expressions. In our findings, the participants reported difficulties in discerning conversation partners' subtle or complex emotional feelings which are often revealed by rather nuanced behaviors, e.g., smile. Additionally, our participants reported more negative emotional feelings (21 quotes) than positive emotional feelings (14 quotes) that they perceived from their conversation partners during face-to-face communication.

In the remaining of this section, we will further generalize and discuss our rich empirical findings along the reported capabilities, limitations as well as design implications.

5.1 Understanding capabilities

Hearing It is viewed as a dominant way for the participants to perceive social signals in face-to-face communication. Participants could perceive conversation partners' feelings about their vocal behaviors (e.g., tone, tempo, energy in the voice). They sense their conversation partners' facial orientation mostly roughly through hearing (i.e., listening to their conversation partners' voice). P14 also mentioned that he could determine whether his conversation partner is leaning forward or backward through listening to his voice. Loss of visual input can enhance the visually impaired people's performance in the remaining sensory modality (e.g., hearing) through compensatory brain reorganization and attention shifts [60]. Such findings are also consistent with the existed mainstream solution in the accessible technology: auditory assistive systems for visually impaired users that adopt auditory signals as the substitution for the vision [61, 62].

Sight Interestingly, we found that the visually impaired participants still rely on the sight to perceive social signals in face-to-face communication. P9 stated: "*If you still have a certain vision, you will rather rely on it*". Seven low-vision participants reported that they could roughly see the certain hand and arm gestures if the gestures are performed through the arm or the whole hand, or in an extended or drastic motion.

Touch Touch is another important modality for the participants to perceive social signals in face-to-face communication. In certain situations, touch can contextually convey intentions and meanings to the participants. For example, hand touch may indicate a stop for talking. Touch can also be used to convey emotions to the participants from their conversation partners, e.g., hugging and shoulder patting express encouraging and supporting.

Obstacle sense Seven quotes describe that the participants can sometimes roughly sense a close-by gesture through obstacle sense in face-to-face communication: P12 was sometimes able to feel certain objects approaching in front of him when his attention was focused, and the surroundings were very quiet. The experimental psychologists have long investigated the obstacle sense [63] and demonstrated that congenitally blind people have the obstacle sense to perceive a nearby object accurately, mostly relying on the spatial auditory information.

Smell P11 described he could identify people by their body smell: "*I can identify different people by their footsteps and smells. The first step is a smell, but sometimes it is cheating. So I also use footsteps as assistance* (*e.g., some people walk slowly, and some others have heavy footsteps*)". Although this participant demonstrated a good olfactory ability to identify people, smelling still has limitations:

(1) Some smells are very similar and sometimes easy to be mixed up;
(2) A person's smell may change after a period. It is not possible for the participant to identify the change, even when it comes from his close friend.

5.2 Understanding limitations

Subtle Information Based on our findings, the participants have limitations of perceiving subtle information in social signals, including finger gestures, gaze, facial expressions, nodding, and handshaking. Many participants could not sense their conversation partners' fingers pointing in certain directions. None of the participants could sense conversation partners' gaze information in face-to-face communication. They seldom realized that gaze behaviors could convey positive emotional expressions (e.g., intimacy, attraction). They had a fuzzy understanding of the gaze and eye contact. None of the participants could sense conversation partners' facial expressions. Since facial expressions link with emotions, participants had difficulties in sensing conversation partners' emotions or feelings in conversations, which may cause misunderstandings in their communication.

Positive Signals We found that the participants reported more negative (21 quotes) than positive emotions (14 quotes) in face-to-face communication. The possibility is they received less positive signals in a conversation due to the lack of sensing subtle gestures and facial expressions from their conversation partners (e.g., eye contact, smile, nod, and thumbs up). Such positive signals can effectively help the participants feel more confident in conversations. On the other hand, it was easier for the participants to sense negative feelings through conversation partners' harsh tone, big and sharp hand/body gestures, or even close the door loudly. P19, for example, could feel the conversation partner was very emotional and angry since that person's body was moving dramatically.

As experienced by the participants, body touch is frequently used to convey positive emotions through their conversation partners (e.g., handshaking, hugging, shoulder patting). However, they receive body touch mostly from people they are quite familiar with, for example, blind students normally do not like body touch unless they are with close friends. According to Ahmed et al. [64], due to the visual impairments, visually impaired people's needs for security and privacy have been strengthened.

Environment The participants hardly distinguish conversation partners' social signals in noisy surroundings (e.g., facial orientation, gestures, and postures). If the surrounding environment is very noisy or crowded, it is very challenging for the participants to sense a conversation partner's facial orientation or gestures and postures. For example, P4 could not decide who was speaking to him if many people were sitting around him. Furthermore, the participants hardly distinguish conversation partners' social signals if their partners are quiet or reticent. Since they cannot use hearing as a compensatory modality in such situations, the participants seldom distinguish their partners' social signals (e.g., facial orientation, gestures, and postures). Thus, they may mistake the conversation partners' real intentions and emotions. Due to a lack of perceiving social signals, the participants have trouble to infer and predict conversation partners' attitudes and the responses (e.g., how a sighted conversation partner will react to them). Therefore, they hardly initiate a conversation and often adopt a passive strategy of participation (such as being just listening) in face-to-face communication [4].

5.3 Generalizing design implications

Based on our findings, we generalize several design implications to inform the design of future HCI systems to support visually impaired users' social signal perception.

As we have presented in the Findings section, the rich results presented in our analysis have yield a broad range of examples encompassing different types of social signals. These examples could contribute vivid empirical understanding about lived experiences of our target group in perceiving social signals, which might help future researchers/designers to identify possible opportunities to study on and design for. Therefore, this subsection aims to further generalize and discuss the implications identified, in order to more explicitly showcase some of the potential design opportunities.

However, several points are to be noted here before presenting our generalized implications. First, our research is intended to provide a wide range of vivid examples, as well as a comprehensive overview of our target group's lived experiences regarding social signals. For this reason, our data gathering and analysis, which are based on a comprehensive taxonomy of social signals [2], have led to a rather broad range of implications. These implications could thereby inform and inspire a wide range of assistive technologies. As a result, our generalized implications and opportunities in this paper are not aimed for developing one single system that incorporates all types of social signals to assist visually impaired users. Instead, our generalized implications and opportunities can be considered separately by researchers/designers when exploring different types of assistive technologies regarding different social signals. It is rather clear that for now, a unitary system supporting all types of mentioned social signals may not be a feasible technological solution in practice. Moreover, based on our data, we believe that in different specific use scenarios, visually impaired users may have different needs regarding social signals. For example, during a face-to-face game (e.g., Werewolves of Miller's Hollow), a visually impaired user may need to be supported in perceiving hand gesture or finger-pointing directions of his/her conversation partners more than other types of social signals. Thereby, when generalizing and discussing each specific implication for design, we will use examples that encompass different types of systems (or using different modalities) rather than an example of a single unitary system that supports users' perception of all the social signals.

Second, the examples which we will use to illustrate each generalized implication are intended to explicitly connect our empirical findings to possible design opportunities. It is for this reason that we have based these examples on current technological solutions, in order to demonstrate how the current available techniques/systems could be feasibly utilized to address the identified opportunities. However, these examples are not intended to serve as ready design concepts for researcher/designers to directly adopt in future research/development. Instead, we believe that by using these examples to concretely explain our identified opportunities, future designers/researchers could ideate their own novel technical or design solutions to address these opportunities. We will now generalize and discuss our design implications and opportunities as follows.

(1) *Facial expressions perception* In our study, we found that all participants could not sense their conversation partners' facial expressions. Due to this, most participants experienced difficulties in discerning conversation partners' subtle or complex feelings. Several systems have been developed for detecting facial expressions, i.e., extracting facial features from the detected face region and analyzing the motion of facial features [16, 17, 28–30]. Such systems provide possibilities for visually impaired people to explicitly receive conversation partners' facial expressions and feelings. For example, Krishna et al. [33] implemented a vibrotactile glove prototype to help a blind user to access facial expressions of a conversation partner. Different vibration patterns stand for seven universal facial expressions of a person. However, identifying seven vibration patterns may increase the cognitive load of visually impaired people and reduce their engagement in conversations. It is not a perfect design solution to convey several kinds of facial expressions to visually impaired people. In the interviews, P19 mentioned he was not sensitive to conversation partners' positive feelings unless he is laughing. Gruebler et al. [65] presented a wearable device that can read positive facial expressions using facial electromyographic signals. This device can be used to detect the conversation partners' smile and happiness and then convert such positive signals to the corresponding auditory or tactile signals that a visually impaired user can perceive. The smile detection technologies encourage visually impaired people to be more confident in conversations.

(2) *Gaze signals perception* As we have found in our study, because of lacking gaze and eye contact, the participants could not catch up the speed of discussions with sighted conversation partners. Lack of eye contact might cause a sighted person to feel that a visually impaired person is not fully engaged in communication [3]. Therefore, HCI designers and developers may consider assisting visually impaired people to perceive gaze signals from the sighted conversation partners and to simulate the appropriated gaze for them as a visual reaction. For example, Qiu et al. [66] proposed a wearable device, namely tactile band, aiming at helping a blind person to feel attention (gaze signals) from a sighted conversation partner (Fig. 3). The tactile band can map the gaze from sighted to the corresponding tactile signal that the blind person can perceive in real time. Qiu et al. [67] also presented a functional work-in-progress prototype, E-Gaze (glasses), an assistive device based on an eye-tracking system. E-Gaze simulates gaze behaviors for visually impaired people as a visual reaction, especially establishing the "eye contact" between blind and sighted people. Many researchers studied gaze behaviors between eastern and western cultures [68–70]. Senju et al. [70] found that Western culture values the maintenance of eye contact, while Eastern culture requires flexible use of eye contact and gaze aversion. Therefore, it is important to implement the gaze model that is aware of cultural distinctions in future work.

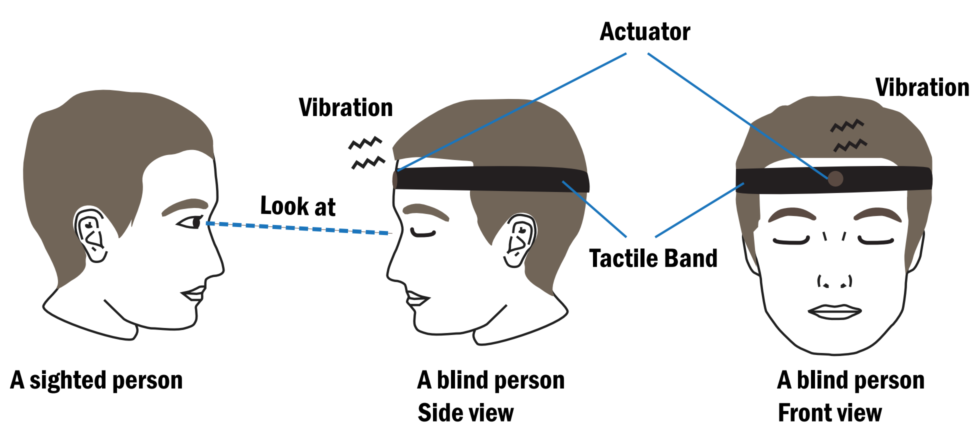

Fig. 3 Design concept of the tactile band, adapted from Fig. 2 [67]

(3) *Head poses recognition* As Utsumi et al. [71] suggested, the head pose is a significant cue for indicating the user attention, conveying rich and interpersonal information. However, our findings suggest that the participants cannot distinguish conversation partners' head poses (e.g., facial orientation, nodding, head shaking) if their conversation partners are not talking or the surrounding is noisy or crowded. Murphy-Chutorian et al. [72] introduced technologies regarding head pose estimation in computer vision, including a full 3D orientation and position of a head. This technology might be used to support visually impaired people to perceive various head poses of their conversation partners. For example, imagine a bracelet that can help a visually impaired person to know who is facing him by using a subtle vibration. Additionally, the auditory feedback via headphones can also support him to know the nodding and head shaking of conversation partners.

(4) *Extending "body touch"* Touch and hearing are both important modalities for visually impaired people to perceive external information. However, as reflected in our findings, touch was more limited than hearing as compensation to the vision for perceiving certain social signals: As indicated by some participants, they only felt comfortable to have body contact with familiar ones. As P20 put, "I don't like to be touched by people during the conversation, but I like to touch things that I cannot see". Therefore, to better leverage touch in social signal perception, the technology could enable actuator-mediated "body touch" without requiring body contact, which may lower the threshold for the visually impaired users to accept "body touch" from less familiar conversation partners. For example, a conversation partner could remotely "nudge" a visually impaired user to quietly or subtly convey certain social intention (e.g., "can I have your attention please?").

(5) *Finger gesture recognition* While considered to be relevant in face-to-face communication, hand or finger gestures, such as finger-pointing (to indicate directions or objects), are difficult for the participants to perceive. Therefore, the technology could be designed to recognize these gestures and translate them into another modality for visually impaired users. For example, a camera-based sensor recognizes the conversation partner's finger-pointing. A wrist-worn multichannel vibrotactile interface then gives a clue to the visually impaired user on which direction the conversation partner is pointing to.

(6) *Shared surrounding with others* As already mentioned, visually impaired people could miss social signals regarding the environment and space, i.e., how their conversation partners interact with the surrounding things, what changes have been made for the local orders of the things, etc. Moreover, as mentioned by the participants, missing such signals can cause inconvenience in face-to-face social interaction. Therefore, the design of computing devices, or Internet of Things systems for certain contexts, could consider how to facilitate the shared use for both sighted users and visually impaired users. For example, an Internet of Things environment designed for a shared space could give relevant and unobtrusive clues to its visually impaired users on what changes (e.g., the placement of the air conditioner remote control) have just been made to the environment by their conversation partners.

(7) *Vision augmentation* As reflected in our data, vision was still quite often reported as an important modality to (roughly) perceive certain social signals. For example, as experienced by some participants (P1, P2, P3, etc.), although they could not see facial expressions of their conversation partners, they can see roughly the big gestures or postures. According to P9, "if you still have a certain vision, you will rather rely on it". Therefore, the technology could also be designed to enhance the visual perception of social signals for visually impaired users. Augmented reality (AR) technology has been widely explored for visually impaired users to recognize others. Ruffieux et al. [73] developed a multimodal AR smart glasses system to help visually impaired people to identify faces. The glasses system provides visually impaired people with both audio and visual feedbacks (e.g., displaying name of the person on the glasses screen). Sandnes [74] interviewed three visually impaired people and identified their main challenge of identifying people's faces in social interactions. Further, Sandnes and Eika [75] introduced a wearable AR display to identify people. By using face recognition software, this wearable device identifies a person and the name is displayed as a textual cue, or a familiar photograph of the person can be displayed. In addition, to identify people's faces, we argue that AR technology could also be used to recognize people's facial

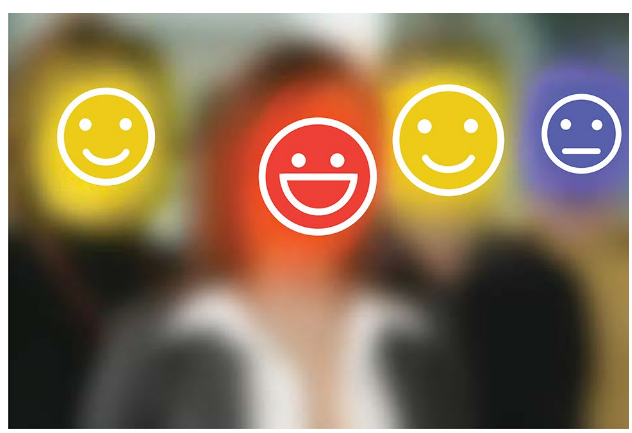

Fig. 4 Example of using AR to assist low-vision users to perceive facial expressions. The AR glasses use facial recognition techniques to sense the facial expressions of user's conversation partners, and superimpose color patches onto their faces as low-res indicators to convey their general types of expressions to the low-vision users

expressions in conversation scenarios. Imagine a pair of AR glasses gives a clue to its visually impaired user on what the conversation partner' facial expression is, through color patch superimposed on their faces (Fig. 4). Figure 4 shows that the AR glasses could use a current facial recognition technique to sense the type of facial expressions a user's conversation partners are having. Then, it can superimpose different color patches onto the faces of the user's conversation partners. This way, through a simple and perceivable color code, a low-vision user might generally tell the mood of his/her conversation partner(s).

5.4 Limitations and future work

In the present section, we acknowledge the limitations of our study and the opportunities for future work. First, the participants' age ranges from 16 to 29, and this relatively young group has a limitation in representing other age groups of visually impaired people, such as the elderly. They experience a gradual loss of vision at later stages of life. Second, in our study, in order to gather a large group of participants with diverse conditions of visual impairment, we conducted our investigations in two different locations: Hong Kong and Yangzhou, which are far from each other. This was one of the reasons that an online interview approach was opted. However, ethnographic interviews could be conducted in the future by similar studies in order to gather richer insights in this topic. Third, in real life, the communicative activities often involve both blind and sighted people. It would also be interesting in the future to investigate lived experiences from the perspective of the sighted: For example, how they experience their conversations with visually impaired people. Such sighted people would be teachers in special education school, parents, and friends, who have plenty of opportunities to communicate with our target group. We may identify new design opportunities from sighted people's interpretations. Finally, in this study, all participants share one cultural background. While this may help us understand social signals under a consistent cultural context, it would be meaningful to also extend our investigation to a multicultural group in the future so that we will be able to understand how cultural differences may influence visually impaired people experience social signals.

6 Conclusion

The qualitative findings in this paper provide concrete and fruitful pieces of evidence toward understanding the social signal perception of visually impaired people. The results of this work would benefit researchers who are studying accessibility technologies. Furthermore, the present work provides a research foundation for further development of accessibility technologies for visually impaired people to improve their social lives. More specifically, to better understand visually impaired people's experiences of social signal perception in face-to-face communication, we conducted online interviews with 20 visually impaired people. Our findings reveal an overview of the participants' lived experiences of their social signal perception. This overview differs from the existing taxonomy based on sighted people's social signal perception. Due to their visual impairment, the participants perceived social signals through their compensatory modalities (e.g., hearing, touch, smell, and the obstacle sense). Different from what was initially expected, sight was still reported by many participants to perceive certain social signals (e.g., rough postures and gestures). Besides, the participants experienced difficulties in discerning conversation partners' feelings since social signals (smile, thumbs up, etc.) sometimes associate with positive feelings. Finally, we identify design opportunities to support visually impaired users' social signal perception such as perceiving facial expressions and head pose, supporting recognizing of finger gestures, as well as promoting inclusiveness of systems for shared use.

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Compliance with ethical standards

Conflict of interest On behalf of all authors, the corresponding author states that there is no conflict of interest.

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