Inclusive Social Virtual Environments: Exploring the Acceptability of Different Navigation and Awareness Techniques

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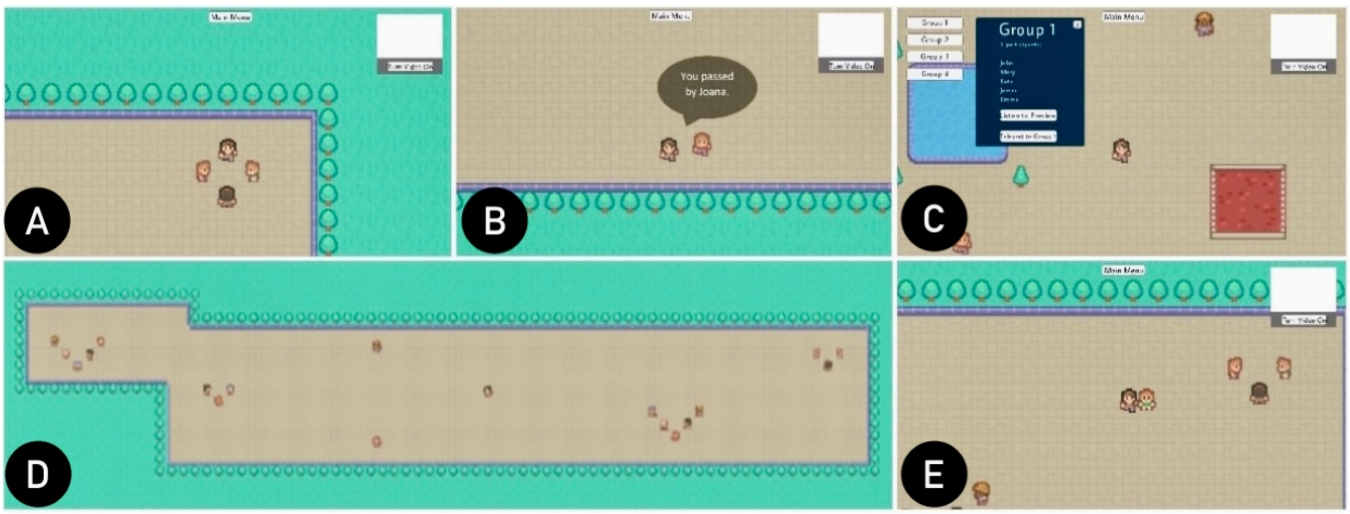

Figure 1: We built a Social Virtual Environment supporting both navigation techniques to support mobility within the virtual space and feedback cues to provide awareness of the users' surroundings. The figure illustrates multiple scenarios used in a user study with blind and sighted people: (A) A group conversation between 4 avatars. (B) When navigating freely in the environment, the user passes by another avatar, receiving audio notifications with the name of the passerby. (C) The user checks information about existent groups in the environment (e.g., number of people, their names, and hears conversation previews) and is able to either Teleport instantly or simulate walking to a particular group. (D) View of the full room used in the study with groups of avatars, individual walking avatars, and the user's avatar. (E) The main avatar is guided by another avatar, in a Co-Pilot scenario.

ABSTRACT

Social virtual environments are becoming more prevalent, replicating and sometimes replacing real-world interactions. Nowadays, such environments are not accessible and end up excluding blind people, due to their strong visual components. In this study, we designed and explored multiple navigation and feedback techniques assessing social acceptability, ease of use, and efficiency. We developed a virtual environment composed of six scenarios to analyze different navigation methods (Free Exploration, Teleport, Auto-Walk, and Co-Pilot) and awareness cues in group conversations (Audio Cues While In-Group Footsteps and In-Group Teleport), and conducted a user study with 8 blind and 8 sighted participants. Our results indicate that participants tend to privilege autonomy and room awareness over efficiency and navigation ease and disapprove of intrusive actions that may jeopardize privacy.

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CCS CONCEPTS

• **Human-centered computing** → **Accessibility systems and tools**; **Empirical studies in accessibility**.

KEYWORDS

Accessibility, Social Virtual Environments, Blind, Social Acceptability, Nonvisual Interaction.

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1 INTRODUCTION

Virtual worlds are increasingly growing in contexts such as work and leisure, allowing people in different locations to interact as if they were together. Platforms such as Gather Town [2] and Mozilla Hubs [1] aim to compensate for the lack of interpersonal interaction experienced in typical video chat calls, by having the users meet in an online world. We will refer to these environments as "social virtual environments". The creation of spaces that replicate real environments has consequences. On the one hand, it provides a sense of physical presence even without leaving the home, but on the other hand, these environments were not designed to welcome everyone [3]. In virtual environments, the majority of spatial information is communicated visually. Human-controlled avatars constantly move in the environment and interact with other avatars and objects, making it challenging for blind people to feel immersed [14]. Consequently, audio and haptic feedback are fundamental for blind people's perception of space, direction, and distance [15, 17, 21].

Prior work on accessible virtual environments has focused on building novel hardware devices (e.g., PHANToM, wearable controllers, or augmented canes[13, 16, 20, 22]) and software solutions (e.g., menus with objects in the environment, echolocation, spatial audio [5, 6, 12, 18]), to support navigation and provide spatial knowledge for blind people. In the context of video games, prior work has also tried to understand blind people's experiences and how to design games that are accessible [4, 9, 10, 19]. Although these solutions may explore navigation and perception of the environment, they are not explored in social environments. VRBubble[14] is an exception (though in a VR context) and stands out by dividing the environment into different social spaces (intimate, personal, and social) and providing spatial audio feedback to convey information on the dynamics of the surrounding avatars. Overall, prior work on virtual environments accessible to blind people tries to convey information on elements (e.g., walls, streets, rooms, objects, or entities) of the environment using varied auditory (or haptic) cues, as a way to convey a greater understanding of the space and support moving therein [7].

Despite these valuable research efforts, virtual environments remain largely inaccessible to blind people. However, they have the potential to surpass the accessibility of the physical world, since the location of all objects, entities, and boundaries are known at all times. This enables designing solutions that would be hard to implement in the physical world given the inherent challenges of accurate localization and tracking. However, little is known about how far we can go in providing accessible navigation and awareness methods that potentially collide with the expectations of privacy by users of the virtual environment (both blind and sighted). Furthermore, because these types of environments are designed to augment the immersion and interaction between users, we must be thoughtful when designing for accessibility and understand whether or not the core motivations can be lost in the pursuit of accessibility.

In this work, we intend to investigate users' preferences when navigating a social virtual environment and interacting with others. Fundamentally, our research questions are:

(1) How are different navigation methods in social spaces perceived by people navigating and in conversations?
(2) Which information should be conveyed (in groups and outside)?

To answer these questions, we explore four different navigation methods and a variety of audio cues to augment social virtual environments. Our goal is to understand the social acceptability, ease of use, and efficiency of each of the proposed techniques by both blind and sighted people. We created a 6-scenario-virtual-environment room using Unity, where users control an avatar in a virtual space and interact with other avatars (Figure 1). In this environment, it is possible to navigate with different techniques, such as exploring the environment autonomously (Free Exploration), moving instantaneously (Teleport), automatically (Auto-Walk), or being guided by others (Co-Pilot). It also provides several audio cues, such as warnings, notifications, or environmental sounds, while users experience various social acceptability plots, such as hearing conversation previews or joining groups with or without announcements. We conducted a user study with 16 participants, 8 blind and 8 sighted. We collected and analyzed participants' opinions, patterns, and preferences regarding the usefulness, acceptability, ease, and efficiency of the experienced awareness and navigation methods. All participants were able to complete all tasks, demonstrating great satisfaction with the experience. While participants' preferences varied, all agreed that it is important to be informed when other users join or hear their group conversations. In general, blind participants tended to privilege autonomy and room awareness over navigation ease and efficiency, and sighted participants privileged the methods they use regularly.

2 SOCIAL VIRTUAL ENVIRONMENTS ACCESSIBLE TO BLIND PEOPLE

Our approach focuses on understanding the social acceptability and preferences of blind and sighted people regarding both different navigation techniques and audio cues/information to provide awareness of the environment (while navigating and while participating in group conversations).

2.1 Design and Implementation

We developed a 2D virtual environment using Unity, which resembles a Gather Town [2] environment. This virtual room (Figure 1, D) has a total area of 808 squares and includes groups of people (represented by avatars) having conversations happening simultaneously at different locations in the environment, about distinct topics. Besides the user's avatar (controlled by the user), all other avatars are non-player characters (NPCs), meaning the environment is a simulation, recreating a real one. Every group has pre-recorded

Awareness Cues	**Scenarios**					
	Free Exploration	Teleport	Auto-Walk	Co-Pilot	In-Group Footsteps	In-Group Teleport
Footsteps	x		x	x	x	
Conversations Afar	x	x	x	x		
Conversation Previews	x	x	x			x
Group Conversations	x	x	x	x	x	x
Joining Groups	x	x	x	x	x	x
Bumping into Walls	x					
Passing by Others	x	x	x	x		
Notifications	x	x	x	x	x	x

Table 1: Awareness Cues available in each Scenario (marked with "x").

conversations that users can join in and listen to. We created scripts for conversations (i.e. small talk about the weather or sports events) which we pre-recorded with a group of volunteers. Other avatars walk in a controlled trajectory that users can pass by.

The camera is centered on the user's avatar which is able to move in the 2D space. We used earcons for representing specific events, such as users turning on/off their own camera (which is displayed on the right-hand side of the screen), and clicking a button. For group conversations and other avatars' footsteps sounds, we used 3D Audio effect to facilitate spatial awareness.

2.2 Navigation and Awareness

We implemented six scenarios aiming at supporting either different navigation techniques (four) or the awareness of group dynamics while participating in a group conversation (two). Throughout these six scenarios, we also provide several auditory awareness cues that are typically conveyed only visually. In particular, we added eight environmental sounds (i.e. footsteps, conversations taking place afar, conversation previews, group conversations, joining groups, bumping into walls, passing by others, and notifications)[Table 1]. We used Text-to-Speech for informative audio notifications such as introductory explanations and warnings when passing by other avatars.

In addition, interactions and audio feedback occur by levels of proximity (similarly to [14], but here in a 2D environment). First, users are prompted to existing groups and conversations through a soft crowd sound (using spatial sound to convey location), mimicking a conversation noise happening afar. Second, they may get information about the group (e.g., number of people and their names) and listen to a Conversation Preview. This aims to replicate walking by a group of people in a real physical environment and perceive what they are talking about. Conversation previews are generated by the selection of 10 seconds taken from the main conversation, which enables one to listen in (i.e. eavesdrop) to the conversation theme and determine whether or not to join the group. Third, when the avatar joins the group, they enter the actual conversation occurring in the group. Furthermore, when users walk by a single avatar, they are informed of who the passerby is. Below we describe the scenarios in further detail.

2.2.1 Navigation-Based Scenarios. There are four scenarios dedicated to navigation techniques:

Free Exploration. The user has the freedom to move the avatar around the environment, by pressing the arrow keys or the corresponding WASD keys. The audio feedback and levels of proximity depend on the actual proximity to a specific group in the environment (from soft crowd noise to information about the conversation, and entering the actual conversation). Feedback on collisions is provided to convey the limits of the environment.

Teleport. The user may navigate a menu of options to go through the different groups and has the opportunity to reach a desired group instantly. It is not possible to freely explore the environment, but rather check which groups are already formed (first proximity level), get quick access to the number and names of participants in each group, as well as conversation previews (second), and the option to join automatically – teleport – a selected group (third) without having to navigate the space or to be close by for inspection.

Auto-Walk. It is very similar to Teleport, but instead of reaching the desired group instantly, the avatar moves autonomously through the environment (producing the corresponding footsteps) to join the selected group.

Co-Pilot. This scenario mimics real-world behavior, where the user can join in with a second person (i.e. co-pilot represented by an autonomous avatar) who guides the user through the environment. Users instead of choosing which conversation they want to join, choose to follow one of the avatars.

2.2.2 Group Awareness-Based Scenarios. In these scenarios, the user is already part of a group conversation. During the conversation, other avatars will join the conversation through different navigation methods. These two scenarios are:

Audio Cues While In-Group Footsteps. The user perceives the approaches of other avatars to the group through the sound of footsteps, followed by a joining earcon sound.

Audio Cues While In-Group Teleport. The user perceives the approaches of other avatars to the group through earcons that indicate that someone is accessing the details of the group and listening to their conversation preview, followed by a joining earcon sound.

2.3 User Study

We conducted a two-part user study, with 8 blind and 8 sighted participants, to understand the social acceptability of different navigation methods and awareness levels in social virtual environments.

Blind Participants					Sighted Participants				
ID	GN	Age	PC	VE	ID	GN	Age	PC	VE
B1	M	63	7	4	S1	F	50	7	3
B2	M	35	5	7	S2	M	52	6	4
B3	M	39	5	3	S3	F	19	6	5
B4	F	40	6	6	S4	F	22	5	1
B5	F	40	4	3	S5	M	25	7	4
B6	M	46	4	1	S6	M	22	6	5
B7	F	61	5	5	S7	M	26	6	7
B8	M	34	7	5	S8	F	22	6	3
Total		M=44.75, SD=10.53	MDN=5, IQR=1.50	MDN=4.50, IQR=2.25	Total		M=29.75, SD=12.44	MDN=6, IQR=0.25	MDN=4, IQR=2

Table 2: Blind and Sighted Participants' answers to the demographics questionnaire. Each participant ranked their experience with computers (PC) and virtual environments (VE) on a scale of 1 to 7, with 1 corresponding to Not Experienced and 7 to Very Experienced.

Both perspectives are important since our goal is to create a welcoming environment for everyone, where blind and sighted users are able to interact with each other. In part one, blind and sighted participants explored four different navigation methods and experienced different information cues. We designed several awareness cues and information to not only allow individuals to autonomously explore the environment, but to enable us to investigate users' perspectives on navigation and augmented awareness for accessibility, and how they related to social norms. Participants experienced navigating the environment, getting information about group conversations happening in the room, joining conversations, and listening to close-by encounters. In part two, all participants experienced being in a conversation while others performed the aforementioned interactions. Participants were not expected nor asked to engage in any conversation, simply to be passive participants.

2.3.1 Participants. We recruited 16 participants, 8 blind and 8 sighted, aged between 19 and 63 (M=37.25,SD=13.75)[Table 2]. Blind participants were recruited from a local institution (*Fundação Raquel e Martin Sain*). Since all participants were volunteers, we were not able to fully control their age or computer experience. However, we did our best to recruit participants of different ages and varied levels of experience with computers and virtual environments, in order to have a representative sample of participants.

2.3.2 Procedure. For each session, we first introduced the project to the participant and asked for permission to record audio and the computer screen. Participants filled in an Informed Consent Form and were asked a demographic questionnaire followed by questions about their experience with computers and remote video conference tools, including ones that use virtual environments [Table 2]. Both blind and sighted participants experienced a session composed of scenarios of the two parts in sequence (detailed below): 1) Navigation-Based; 2) Group Awareness-Based.

The average duration of the sessions was 45 minutes for blind participants and 30 minutes for sighted participants. Sessions were held in person, and participants used a laptop and headphones provided to interact with the virtual environment (with cleaning between participants). Between each scenario, we introduced the upcoming steps: Participants were asked to listen carefully to an introductory instruction of each scenario on how to navigate in the environment. They were given the chance to replay that informative audio again at any time (by pressing the I keyboard key), to pause the audio (by pressing P) or to stop the audio (by pressing Z).

Participants were presented with the virtual environment and given a sequence of tasks to do in order to experience all of the navigation/awareness techniques in context. In between experiencing different techniques, we asked participants to share their thoughts on the experience. One researcher took notes during the experience and later re-played the recordings to look into specific moments in detail. All recordings were re-watched and every task was resumed and timed. Both study parts are detailed below.

Part One: Navigating the Environment. Participants completed different tasks when experiencing the different navigation techniques. For each scenario, they were given a set of tasks, which would require them to experience a set of awareness cues. In all of them, participants had to find a specific group.

(1) **Free Exploration**: participants were asked to explore the environment in order to find a certain group by the conversation theme or the name of a specific person in the group. We introduced conversation cues, footsteps, feedback on collisions, and feedback on passersby avatars. Participants could also turn their camera on and off;
(2) **Teleport**: participants were asked to find out how many groups were in the virtual room, the details of the groups, hear previews of their conversations, and teleporting to a specific group by the conversation theme or the name of a certain person;
(3) **Auto-Walk**: tasks were very similar to the Teleport scenario, but participants walked automatically to a specific group instead of teleporting;
(4) **Co-Pilot**: participants were asked to find who was near their avatar, select a specific one as a guide and follow along with the co-pilot in order to join a new group.

Part Two: In Conversation. Participants started in a group conversation. While in this conversation, participants experienced a sequence of events to illustrate different navigation and awareness techniques (executed by others) while they are in a conversation.

(1) **In-Group Footsteps**: participants were asked to be aware of what was happening: 2 new members joined the group by walking (footsteps) - the first with, and the second without, his name announced;

	Blind Participants				Sighted Participants			
Scenarios	**Time Spent M (SD)**	**Navigation Ease MDN (IQR)**	**Navigation Acceptability MDN (IQR)**	**Navigation Efficiency MDN (IQR)**	**Time Spent M (SD)**	**Navigation Ease MDN (IQR)**	**Navigation Acceptability MDN (IQR)**	**Navigation Efficiency MDN (IQR)**
Free Exploration	10m08s (02m01s)	6.50 (2.00)	7.00 (0.50)	6.50 (2.25)	03m41s (00m47s)	7.00 (0.00)	7.00 (0.00)	6.25 (2.00)
Teleport	03m15s (01m28s)	7.00 (0.25)	6.00 (2.00)	7.00 (1.00)	01m58s (00m36s)	7.00 (0.00)	7.00 (0.25)	7.00 (0.00)
Auto-Walk	02m41s (00m38s)	7.00 (0.25)	6.50 (1.50)	6.50 (1.00)	01m51s (00m19s)	7.00 (0.00)	7.00 (2.00)	7.00 (1.50)
Co-Pilot	00m25s (00m07s)	7.00 (0.25)	7.00 (1.50)	7.00 (1.00)	00m19s (00m03s)	7.00 (0.25)	6.00 (1.25)	6.50 (1.25)

Table 3: Time Spent and Ratings of Each Scenario in Part One of the User Study by Blind and Sighted Participants.

Participants	Instructions MDN (IQR)	Footsteps MDN (IQR)	Crowd MDN (IQR)	Nr Groups MDN (IQR)	Names MDN (IQR)	Details Afar MDN (IQR)	Previews MDN (IQR)	Teleport MDN (IQR)
Blind	7.00 (0.00)	7.00 (1.00)	6.00 (1.25)	7.00 (0.25)	7.00 (0.00)	7.00 (0.25)	7.00 (0.25)	4.50 (2.50)
Sighted	6.00 (2.25)	7.00 (1.00)	6.00 (2.25)	6.50 (1.50)	7.00 (1.00)	6.50 (1.00)	7.00 (0.00)	5.00 (2.25)

Table 4: Ratings of the Acceptability of Each Awareness Technique of the User Study by Blind and Sighted Participants.

(2) **In-Group Teleport**: participants were asked to be aware of what was happening: 2 new members joined the group by teleport, with 3 audio notifications(earcons): 1) group details (size and names), 2) conversation preview, and 3) group joining sound - the first one with and the second one without his name announced;

At the end of the session, we asked participants to fill in a questionnaire with Likert items regarding their perceptions about the scenarios explored, the ease/difficulty and efficiency they felt when using them, as well as the social acceptability of each of the techniques (rated on a scale of 1 to 7). Lastly, we conducted a debriefing semi-structured interview, where we focused on participants' perspectives on the different navigation types, and awareness abilities within a virtual environment, as well as on reflecting on the social norms of virtual spaces, and how navigation and awareness can/should be designed to be both inclusive and unobtrusive to all. The answers to open questions were compared in order to find common patterns and opinions.

3 FINDINGS

In this section, we present both quantitative results related to timings and ratings given by participants and a preliminary qualitative analysis based on observations and semi-structured interviews.

3.1 Quantitative Analysis

The average time spent completing Part One tasks was approximately 16 minutes (M=16m29s, SD=04m14s) for blind participants and 8 minutes (M=07m49s, SD=01m45s) for sighted participants, excluding the time researchers spent explaining the study to participants. Part Two took an average of 2 minutes (M=02m20s, SD=00m22s) for blind participants and 1 minute (M=01m17s, SD=00m10s) for sighted participants to complete. The scenario that demonstrates a greater time difference between blind and sighted participants is Free Exploration [Table 3]. While sighted participants went directly to each group to find the desired conversation theme or participant name, blind participants tried first to get a sense of the room they were exploring. Most participants moved towards the top/bottom wall until hearing a collision sound and then moved in the opposite direction to collide with the opposing wall. Once those limits were captured, they moved along the wall to the right/left, until finding a corner, and so on. In this way, they were able to obtain a mental map of the room, and only at that stage, they were focused on finding the desired group. In general, while searching for a specific formed group, blind participants walked close to the walls as guiding lines, which is a common strategy used by blind people when navigating the real world [8, 11].

To understand participants' preferences on the navigation methods experienced in Part One, we asked them to classify the ease, acceptability, and efficiency (e.g., Free Exploration is an efficient navigation method) of those methods on a scale of 1 to 7, with 1 corresponding to Strongly Agree and 7 to Strongly Disagree [Table 3]. On average, both sighted and blind participants elected Teleport as the most efficient navigation method, and Free Exploration as the least efficient, but the most acceptable form of navigation [Table 3].

Awareness techniques provided by audio cues were also rated on a scale of 1 (Strongly Disagree) to 7 (Strongly Agree). Audio instructions, footstep sounds, soft crowd conversation sound, and getting access to groups' number of participants and their names, even from afar, were considered useful [Table 4].

Part Two focused on the awareness of group dynamics and on their acceptability. By being part of a group, participants were able to consider a different perspective. When pondering the perspective of searching for a group, participants considered hearing parts of a conversation without being involved in that group, from anywhere in the virtual environment, more acceptable than teleporting to a group without announcement [Table 4]. However, when asked if group members should be notified that someone is listening to their conversation, all participants replied "Yes". Moreover, all blind and 5 sighted participants replied that the name of that person must also be announced.

3.2 Qualitative analysis

We derived a set of lessons learned from the user study based on observations, interviews, and a preliminary qualitative analysis alongside the quantitative results presented above. The themes were first proposed by the researcher who conducted the study sessions. All themes were discussed and iterated with the research team.

Privilege autonomy over efficiency. Despite being the most challenging navigation method for blind participants, Free Exploration offers an autonomous exploration of the virtual environment. Users appreciate fully controlling their avatars and discovering the surroundings (e.g., B4: *"I like to control, to go wherever I want"*), allowing them to create a mental map of the room. Blind and sighted participants mentioned that Free Exploration gives more autonomy and control over the avatar, which further increased their engagement with the tasks. Even when mentioning the Co-Pilot scenario as acceptable, efficient, and easy to navigate, blind participants preferred to do it by themselves and not with the help of a guide. For sighted participants, Co-Pilot was ranked the least acceptable form of navigation since they do not identify with having a guide in real life, and consequently, with this navigation method.

Trade-offs between difficulty, efficiency, and room awareness. For blind participants, Teleport was elected as the easiest and most efficient navigation method, but the least acceptable. Teleport makes it easier and quicker to access groups when compared to other forms of navigation. However, it does not provide the ability to capture the configuration of the room. In contrast, Free Exploration was voted the most difficult and less efficient navigation method to use. Nonetheless, it was chosen as the most acceptable form of navigating in the virtual environment, as it supports space exploration and distance perception. Still, there are advantages in both methods, as highlighted by B1: *"Teleport is my dream. It is very easy through the information given to go straight to the group you want. There is the downside of not realizing the configuration of the groups in the room. Free Exploration has the charm of being a challenge and allowing you to get to know the configuration of the room"*.

Flexible navigation, no clear preferred method. Although there is no clear favorite, blind participants reported that Auto-Walk is a well-balanced navigation method. B8 said that *"It has the efficiency of Teleport, but the footsteps sound of Free Exploration, which also contributes to sense distances and to warn group members that you are approaching them"*. For sighted participants, Free Exploration is intuitive since it feels like playing a common game. Teleport has the advantage of efficiency, something that Auto-Walk loses for taking longer to achieve the same goals.

Audio feedback is essential for blind people, but redundant for sighted people. In general, participants considered audio feedback – e.g., footsteps sounds and soft crowd conversation sound – useful and helpful in contributing to an immersive virtual environment. Blind participants found such feedback similar to the real world, as reported by B4: *"It really sounds like a person is walking!"*. Most importantly, audio feedback was vital to capture the environment dynamics enabling participants to reach their goals. Sighted participants, on the other hand, found the audio instructions redundant, which was expected since they were also presented visually. S7 mentioned that: *"The audio is very explanatory for blind people, which is quite adequate. However, for sighted people, it ends up being a lot of information"*.

Participants privilege access to information, even from afar. Both blind and sighted participants appreciated receiving informative feedback about their surroundings. This includes being able to access the overall number of groups and people's names and details, even from afar. Participants considered conversation previews acceptable as long as group members are notified that someone (and who) is listening to their conversation. However, this may not be usable in crowded virtual environments where many such notifications can become disruptive for group members.

4 CONCLUSION AND FUTURE WORK

We developed an accessible social virtual environment that replicates a room with groups of people having conversations, in which blind and sighted users are able to experience different navigation methods and get audio feedback about their surroundings. In an exploratory study where both blind and sighted participants tried out the different techniques, we found that participants reprove intrusive actions without permission, such as joining or hearing their group conversation without a previous announcement. Also, blind participants privileged autonomy and room awareness over navigation ease and efficiency, whereas sighted users privilege their regular interaction mechanisms. Future work can explore novel exploration methods and auditory cues, particularly focused on improving the efficiency of autonomous exploration methods and on further enriching the environment with natural audio cues that convey social meaning.

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