Disorientation Factors that Affect the Situation Awareness of the Visually Impaired Individuals in Unfamiliar Indoor Environments

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Abstract. Developing situational awareness for individuals with visual impairments can be a challenging process, as designers need to understand the environmental aspects as well as the users' needs. In unfamiliar indoor open spaces, individuals with visual impairments need to work around multiple disorientation factors that can affect their orientation and situation awareness levels. In this work, we report our experience and results of longitudinal user studies that were designed to facilitate cues that help raise the situation awareness level of individuals with visual impairments when exploring unfamiliar indoor open spaces. Through our results, we explain in detail users' disorientation factors in such environments.

1 Introduction

Situational awareness (SA) can be explained as the individual's current understanding of the environmental elements and their changes [1]. Picking up environmental cues, such as auditory, can help in maintaining high SA. However, there are some factors that affect this process. In this work, we explain the disorientation factors that we gained through the conduction of three user studies that were designed to formulate our system and SA requirements for an assistive orientation technology to aid individuals with visual impairments in unfamiliar indoors [2]. In our previous paper, we briefly discussed the disorientation factors that affect individuals with visual impairments when obtaining environmental cues in unfamiliar indoor spaces [3]. In this paper, we expand and elaborate upon these factors by providing a detailed user experience.

The aim of this paper is to provide insight for the designers of indoor orientation assistive technologies about the factors that affect users' orientation to be taken into account when designing. The contribution can be summarized as uncovering in detail the disorientation factors that affect the orientation of individuals with visual impairments in unfamiliar indoor open spaces. Using feedback from 95 participants in three different studies, we will shed light on factors and concerns that relate to the visually impaired individual's orientation

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in unfamiliar indoor open spaces, such as atriums. Also, we will discuss some implications of designing orientation assistive technologies that were drawn from our results. Understanding the ways that target users orient themselves within environments can provide helpful insight into the design.

2 Related Work

In the past much work has discussed orientation-related issues for individuals with visual impairments. Some work focuses on the orientation process from an orientation point-of-view [4–7], while others focus on providing requirements of indoor assistive technologies [2,8–11]. While the previous work discusses many important issues that relate to the orientation tasks, they do not discuss disorientation factors that can affect users' SA. In this research, we highlight users' experience with the factors that can affect their orientation abilities for the purpose of eliciting requirements for indoor orientation aids. In the rest of this section, we will review examples from each of the previous categories.

Banovic *et al.* [7] describe two user studies where they examined the ways in which individuals who are visually impaired identify surroundings in unfamiliar environments. The first was conducted as a high-level learning study. The researchers initially interviewed nine participants. Participants were then asked to perform exploration tasks in two different outdoor spaces. The second study was directed toward the activities that help individuals who are visually impaired to develop a cognitive map of their environment. Participants were asked to perform two tasks: (1) answer a set of questions that relate to a familiar environment, (2) physically navigate paths that are less familiar to each participant. After completion of the exploration tasks, semi-structured interviews were conducted. Findings from the second study suggested that large indoor spaces were difficult for participants to explore and learn. In our work, we looked into the factors that affect the orientation process in unfamiliar indoor environments and how users employ their skills to overcome them.

Miao, *et al.* [8] elicited requirements to build an indoor navigation system (MOBILITY project) that is intended to provide independence to blind travelers. They interviewed six blind participants and triangulated their interviews with an orientation and mobility (O&M) instructor. They employed structured interviews in their elicitation process. In their paper, they provided proposed functionality to be included in the system such as: contextual information about the surroundings as well as basic building information. In terms of learning the way blind individuals perceive information from the environment, they discussed such issues with the O&M instructor. Also, one of their developers wore a blindfold where he/she experienced non-visual travel.

3 User Studies

In this work, we present a series of three studies: (1) a domain understanding study, (2) Orientation and Mobility (O&M) recommendations, and (3) user survey. The results of each study were used to tailor the design of the next one to enhance the outcomes.

3.1 Methodology

Two of our user studies; domain understanding and O&M recommendations; were presented in the form of semi-structured interviews, while the third study was a validation study in the form of an online survey. To analyze our results, we applied the following qualitative techniques: content analysis [12], and open coding method that is a part of the grounded theory method [13]. Due to the relevance of the three user studies that we conducted the results are collated and can be found in Sect. 5. All studies received ethical approval from the university's IRB.

3.2 Study 1: Domain Understanding

This study was designed to help us understand the domain of indoor orientation and navigation for individuals with visual impairments. We interviewed 24 participants from six different countries to examine the strategies, which are employed to navigate through an unfamiliar indoor environment. This includes identifying the day-to-day challenges faced by individuals with visual impairments when orienting or when locating objects within their vicinity. We also initially investigated users' experience with other indoor orientation and navigation assistive technologies, and their views on accepting new forms of technologies. Participants were recruited from different countries to help us elicit requirements that assist in building an international solution. We designed this user study in the form of semi-structured phone interviews with 66 questions, of which 21 were open-ended and 45 were close-ended. Interview questions were divided into the following categories:

- Mobility issues in indoor environments
- Identification of indoor orientation and navigation tasks
- Identification of frustrations and concerns in different indoor environments
- Exposure and experience with indoor orientation assistive technologies
- User interface and technology preferences for indoor orientation assistive technologies

Participants were recruited through online mailing lists. Table 1 provides a classification of our participants depending on their level of functional vision and the mobility aid they use. *G* denotes participants who primarily use guide-dogs, while *C* refers to participants who mainly use canes. The mean age was 49.2 years (14.8 SD). Five of the participants were legally blind, yet could rely on some levels of functional vision, while 19 were fully blind. Legally blind are defined by the US Social Security as persons whose visual acuity is 20/200 or less in the better eye with best sight correction [14]. Twelve among the participants who reported being fully blind were born blind, while the rest lost their vision at a later point. Eleven of our participants primarily use guide-dogs to assist them when traveling, while the remaining 13 used canes. Twenty-three of our participants have received the O&M training.

Table 1. A classification of participants depending on the level of functional vision, mobility aid and geographical locations.

Legally blind	Totally blind	Country	Count
-	G21	Australia	1
-	G3	Canada	1
C17	-	Italy	1
G15	-	New Zealand	1
C11	-	UK	1
C2, G12, G23	C1, C4, C5, C6, C7 C8, G9, G10, G13, C14, G16, G18, C19, C20, C22, G24	USA	19
Total			24

3.3 Study 2: Orientation and Mobility Recommendations

From the previous study, we found that most of the navigation related problems in unfamiliar indoor environments can be categorized into: (1) maintaining orientation, (2) locating a path, and (3) detecting obstacles. Maintaining orientation when entering unfamiliar indoor environments includes but is not limited to understanding the spatial layout of objects within the environment, keeping track of the direction which the user is traveling in, and identifying landmarks that are related to the user's mission. Locating a path was another concern of the participants. The third need was detecting obstacles using their current aid, particularly those which would require time and effort to perceive. The indoor obstacles reported included objects above user's waist and floor signs. One notable aspect regarding participants in our first study was that users with service-animals were less concerned about orientation and obstacles, compared to users with canes. This guided us to reshape our goal and focus mainly on the orientation of cane users as it can greatly impact other challenges. To complement our findings relating to the indoor orientation challenges, we interviewed six certified O&M instructors, as they could provide a unique insight into the behavior of individuals with visual impairments, and the safe practices that enhance their orientation in unfamiliar indoor spaces. We focused our interviews on atrium areas as an example of open spaces and challenging indoor setup. We also discussed the best practices for individuals with visual impairments to navigate indoors from an O&M instructors' point of view.

Participants were recruited through online mailing lists. Participant demographics are shown in Table 2. Three of the participants selected were male, while the other three selected were females. Participants' mean age was 50.5 years (11.9 SD). The oldest participant was 60 years old and the youngest was 27. Participants came from five different states: Pennsylvania, Kentucky, Nebraska, New Mexico, and California. Two of the instructors were sighted, while the other four were visually impaired. Three of the visually impaired were blind since birth, while the remaining instructor lost her sight more than five years

Table 2. Key facts about O&M study participants.

ID	Location	Age	Sex	O&M Experience	Vision
O1	US-CA	53	F	3+ years	Sighted
O2	US-KY	60	F	3+ years	Sighted
O3	US-PA	57	M	3+ years	Blind
O4	US-NE	55	M	3+ years	Blind
O5	US-NM	27	F	Less than a year	Blind
O6	US-KY	51	M	3+ years	Blind

ago. Except one, all instructors had more than three years experience in O&M training. The exception was a new instructor who had less than a year of O&M teaching experience.

3.4 Study 3: Online Survey

As a follow up to our previous user studies, we conducted a third study in the form of an accessible survey. The objective behind our study was to validate and expand our previous findings, as well as to identify initial requirements as the basis for our design. To obtain a wider sample of participants, we recruited via a number of platforms including online mailing lists, social news lists such as reddit.com, emailing previous participants, in addition to word-of-mouth (by those in the aforementioned groups).

Through our previous studies, we have found that the difficulties with orienting one's position occurs more with individuals with visual impairments who rely on their cane to navigate unfamiliar buildings. This, however, guided us to tailor our survey to be more specific to cane users. Additionally, we did not focus on individuals with secondary disability. Our selection criteria can be summarized as any individual with visual impairment who is: an adult, uses a cane only, not hard-of-hearing or deaf, and able to walk unassisted.

Our survey was composed of 27 questions. Different types of question styles were employed including multiple choice, discussion questions and attitudinal questions. We received 65 responses. Participants' mean age was 53.26 years (11.29 SD). The range between participants' ages was 51 years, where the youngest participant was 20 years old and the oldest was 71 years old. The male-female ratio was about half where 32 were female, 31 male, and two preferred not to answer. Table 3 shows a categorization of participants in terms of ages and visual impairment types. We had participants from 27 different geographical locations inside and outside the United States (US). The majority of the participants are from the US (56 participants). Two of our participants preferred not to reveal their location. In terms of the visual impairment types, 41 (63.1 %) of our sample reported that they are totally blind while 24 (36.9 %) of them reported being legally blind. Depending on their age groups, we have categorized our sample under four categories (see Table 3). In terms of sight condition and cane usage, 44 (67.7 %) of our participants reported that they have been

Table 3. Survey participants categorized in age groups and their functional vision.

Age Groups	Gender	Legally blind	Totally blind	Count
18–29	Male	-	-	4 (6.2 %)
	Female	S11, S23	S51, S52	
30–49	Male	S27, S29	S13, S19, S26, S34, S62	12 (18.5 %)
	Female	S25, S37, S53, S41	S54	
50–64	Male	S10, S36, S38, S43, S60, S65	S5, S9, S14, S15, S20, S31, S33, S39, S44, S49, S61, S63, S64	39 (60.0 %)
	Female	S12, S28, S30, S47, S57	S2, S3, S4, S6, S7, S8, S16, S17, S18, S32, S35, S50, S55, S56, S58	
65+	Male	S45, S46, S48, S24	-	7 (10.8 %)
	Female	-	S21, S40	
	No answer	S1	-	
No answer	Male	S22	-	3 (4.6 %)
	Female	-	S42	
	No answer	S59	-	
Total				65

visually impaired since birth, while 21 (32.3 %) of them reported that they were pronounced as individuals with visual impairments more than 5 years ago. Fifty-six participants (86.2 %) stated that they received their O&M training more than five years ago, one (1.5 %) received the training between 3–5 years ago, seven (10.8 %) received their O&M training less than a year ago, and one did not answer the question. Fifty-eight (89.2 %) participants had an experience of using their cane for more than five years, two (3.1 %) had an experience between 3–5 years, and five participants did not answer our questions.

4 Background

In this section, we provide some relevant results, which are important to understanding the context of our resulted disorientation factors. The sections provided here resulted from our user studies and aligned with the previous research that was designed to facilitate experience of individuals with visual impairments when exploring unfamiliar indoors.

4.1 Environmental Cues

Paying attention to the environmental cues was reported by O&M instructors as well as the other participants as an important factor that help in gaining a good sense of orientation. Our participants mentioned different cue types that help when exploring unknown indoor environments: auditory, tactile, and olfactory. Auditory cues were often reported as the primary way for users to understand environments. Tactile feedback and olfactory cues were mentioned as well as an important indicator to understand the indoor environment. Participants who primarily use canes appeared to spend more time and effort paying careful attention to environmental cues compared to guide-dog users. In our first study, participants who use guide-dogs reported pausing for moments when entering unfamiliar buildings, while cane users reported pausing for a few *minutes*. For example, participant C1 said "probably the first thing I would do, is get inside and just stand still for a minute and listen. And if there is an elevator I would hear people using it, if it is a busy building that is, or if I'm going to a doctor's office, there would be a receptionist behind the desk you can hear these machines that he/she is using (sic). So, I'd listen for clues [...] to where I might be and then I just start going and see what I come to". This is an important step, as cane users need to have a preliminary understanding of the potential objects and obstacles within an environment before moving forward to walk through it. On the other hand, guide-dog users pause to get a general sense of the environment. Participant G3 said "I usually would stop and listen to get a general sense of my surrounding and then direct my dog accordingly"; however he added, "then I would tell the dog 'go forward' and 'find elevator' or 'stairs'." This is an example that shows that guide-dog users rely on their dogs to orient them in unfamiliar indoor buildings.

Olfactory cues could provide users with information about their surroundings, especially when searching for a landmark that is associated with a unique smell, for example, a coffee shop. However, participants in our first study as well as O&M instructors stated that smells can be used as helpful indicators but should not be treated as a permanent cue. The reason is that olfactory cues may not always be presented due to reasons such as closed doors on the landmark that produce them.

Participants reported the importance of tactile cues when learning and exploring unknown indoor environments. Except for signs, tactile cues can be obtained when individuals with visual impairments finish constructing their initial mental map of layout by listening to the sounds in the environment. Things like floor texture, and feedback from the cane, can help the user to acquire more information about the environment. For example, a floor mat can be an indicator of the building entrance. Another example is the change in the floor texture, which indicates to the individuals with visual impairments that they transitioned to a different part of the building.

4.2 Exploration Strategies

Our participants in the first study reported different techniques and steps that they perform when entering an unknown building. As we decided to focus our design to assist cane users, we investigated the recommended strategies to explore unfamiliar indoor open spaces from the O&M instructors' point of view.

Some of the instructors explain techniques they teach their students when orienting in unfamiliar buildings. Although the O&M instructors we interviewed have different O&M approaches, most of the practices described by them were similar. For example, encouraging the students to learn about the environment while exploring it was a common recommendation. This includes paying attention to the auditory cues such as unique landmark sounds, which can help in indicating the presence of certain landmarks in the environment.

Learning about unfamiliar indoor open spaces can be difficult, as individuals with visual impairments need to construct an initial mental map by listening to the environment and keep updating that initial mental map when they navigate it. Two techniques mentioned by O&M instructors were:

1. Perimeter search: when an individual with visual impairments tries to understand and mentally-map an indoor open space. The individual with visual impairments trails the wall next to his/her side and follows the walls around the space until he/she comes back to the original position. While the individual with visual impairments is trailing walls, he/she tries to collect cues about the landmarks and obstacles near the walls. This strategy gives the individual with visual impairments the ability to understand the environment; however, it might not allow them to understand the area in the middle of the open space.
2. Grid search: when an individual with visual impairments enters an indoor open space, and after paying attention to the environmental cues, he/she starts exploring the space by checking the back side wall (the wall at the beginning of the building), then the user tries to cross the space to the other side and trails the opposite wall. This technique can allow any individual with visual impairments to understand the atrium area and build a better mental map than those who rely only on their perception when standing at the entrance to the building.

Both of the previous reported techniques are aligned with the techniques reported by Jacobson [4]. With the previous techniques, individuals with visual impairments can learn more about the environment if they have the desire to visit that environment in the future.

4.3 User Needs

When visiting unfamiliar indoor environments, individuals with visual impairments expressed their need to understand more than their path information for the purpose of visiting such environments in the future. Among the needs provided: layout understanding, guidance, and obstacle detection. Due to the scope of this paper, we will not provide details about the user needs. More details about user needs as well as user and situation awareness (SA) requirements can be found in our previous paper [2].

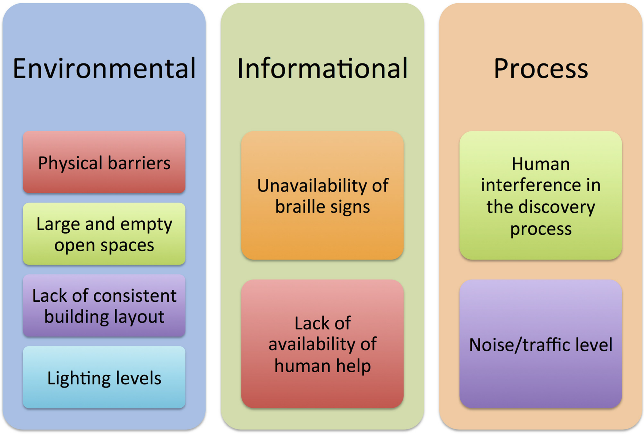

Fig. 1. Disorientation factors in open spaces indoors.

5 Results

In this section, we discuss our findings that relate to the orientation of individuals with visual impairments in unfamiliar indoor open spaces. We have collated our studies' results due to the relevance between the three studies.

5.1 Disorientation Factors

We coded the feedback that was provided by the participants in our validation study (study 3) to formulate the disorientation factors. We used standard coding process [13]. Our coded disorientation factors can be grouped under three categories depending on their context: environmental, informational, and process. Figure 1 shows the disorientation factors under their categories.

Environmental Factors. can cause disorientation to individuals with visual impairments. We coded four types under this category. Physical barriers that separate landmarks from the space where the individuals is located can contribute to a low orientation. Examples of this type are elevators behind walls and reception desks behind closed doors. Such barriers can isolate the auditory cues that are generated from these landmarks, which can lead to a disorientation. The second type under environmental categories is empty space. With fewer landmarks that individuals with visual impairments can relate-to when traveling open spaces makes it harder to travel and rely on a reference point when traveling. Lack of consistent building layout is the fourth type. Stylish and weird building shapes and designs can bring disorientation to the individuals. Such individuals would expect buildings to follow a similar fashion of the ones they experienced. The final type under environmental factors is the lighting levels. Individuals with visual impairments who have little perception to the light might suffer from bright and strong lighting setups indoors. Such lighting effects might generate glare and cause disorientation. An example of this is what participant S28 said, "I wear a hat to manage light and glare..."

Informational Factors. can be generally explained as a lack of information in any indoor environment. There are two types under this category: unavailability of braille signs as well as the lack of human help. Braille signs provide good information about a building and rooms; if they're missing or not in a place where an individual with visual impairments expected them to be, they can cause disorientation. Also, if a sign is installed upside down.

Process Factors. are those encountered factors that can affect the orientation process. We have coded two types under this category: human interference as well as noise and traffic levels. If an individual with visual impairments is listening to the environment and pedestrian traffic is going on around him/her, it is difficult for them to pay close attention. Also, extreme cases of building noise can cause disorientation. In high noise, individuals with visual impairments cannot listen for cues as such cues can be masked. In silent environments, many auditory cues are missing as well.

6 Design Implication on Assistive Orientation Tools

Through the course of our user studies, we elicited much feedback from users where they expressed their needs and preferences in orientation assistive tools as well as how to interact with them. We transformed users' feedback into design implications that can help design for orientation and navigation systems. In this section, we will briefly discuss each guideline.

Adapt to Environmental Changes. As mentioned before, noise and pedestrian activity levels can affect individuals with visual impairments when exploring unfamiliar indoor environments. In such environments, noise and traffic levels can affect the voice feedback provided by any system by interfering or masking its feedback. Also, it becomes much harder to work with voice recognition technologies in such environments. Assistive orientation technologies need to provide different input and output modalities that can help users interact with the system.

Provide Information Beyond User's Context. Systems in such environments need to consider giving users more abstract details about the indoor environment beyond their current context. For example, landmarks that are out of the current user space can be beneficial. In some cases, individuals with visual impairments look for landmarks that do not exist in the atrium area. Also, users would benefit from general information about the atrium such as shape and size.

Support User's Situation Awareness. A goal can be achieved by different tasks. When designing assistive technologies to aid individuals with visual impairments' orientation, it is important to design with user goals in mind not only how to achieve the tasks. Indoor orientation goals can be divided under three goals: obtaining initial mental map, maintaining high orientation, and performing good mobility. Designing to support such goals can help the users to achieve them regardless of their tasks. Our previous paper [2] provided a detailed Goal-Directed Task Analysis (GDTA) [15] for indoor orientation for individuals with visual impairments.

7 Conclusion and Future Work

To maintain their orientation, individuals with visual impairments need to acclimate to many factors that can be present in indoor environments. In this work, we discussed the disorientation factors that can affect individuals with visual impairments' SA indoors. Our results suggest that these factors can be categorized into three groups: environmental, informational, and process factors. Our results can help other researchers who are designing assistive technologies that aid the visually impaired indoors by providing them with insight about some factors that can be taken into account when designing.

Our next step is to incorporate our results in the design process. Soon, we will start our prototyping stage. Later, with help from a number of target users, we will test and validate our prototypes.

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