Research Article

BJVI

British Journal of Visual Impairment
1–13

DOI: 10.1177/0264619619833723
journals.sagepub.com/home/jvi
SAGE

Indoor navigation by blind people: Behaviors and challenges in unfamiliar spaces and buildings

Watthanasak Jeamwatthanachai, Mike Wald and Gary Wills
University of Southampton, UK

Abstract

A number of visually impaired people suffer from navigation-related activities due to mishaps that discourage them from going out for social activities and interactionsn contrast to outdoors, traveling inside public spaces is a different story, as many environmental cues cannot be used and have their own set of difficulties. Some technologies have come into play in helping these people to have freedom in navigation (e.g., accessible map, indoor navigation systems, and wearable computing devices). However, technologies like accessible maps or indoor navigation systems are insufficient to fulfill the independent navigation gap as additional information is required (obstacles, barriers, and accessibility). To promote indoor navigation and create better use of technologies for visually impaired people, it is essential to understand the facts and actual problems that they experience, and what behaviors and strategies they use to overcome any problems; these are the concerns that led to this study. In all, 30 visually impaired people and 15 experts were recruited to give an interview about the behavior and strategies used to navigate indoor spaces, especially public spaces, for example, universities, hospitals, malls, museums, and airports. The findings from this study reveal that navigating inside buildings and public spaces full of unfamiliar features is too difficult to attempt the first time for a number of reasons, reducing their confidence in independent navigation.

Keywords

Behaviors, blindness, indoor navigation, public spaces, strategies, unfamiliar spaces, visual impairment, wayfinding

Introduction

In 2014, the World Health Organization (2014) estimated the number of visually impaired people at 285 million worldwide, of which 39 million are blind and 246 million have low vision. Lack of vision creates difficulties that directly affect most activities, especially those requiring the ability to navigate. Being unable to obtain information about where they are or where to go in public buildings, such as colleges/universities, malls, hospitals, public transportations, and airports,

Corresponding author:
Watthanasak Jeamwatthanachai, Cyber Physical Systems Research Group, Department of Electronics and Computer Science, University of Southampton, Southampton SO17 1BJ, UK.
Email: wj1g14@ecs.soton.ac.uk

causes problems in their wayfinding process, discouraging them to go out by themselves. The study found that 80%–90% of visually impaired people spent their life inside buildings (Li & Lee, 2010).

For visually impaired people, doing such things would not be as easy as sighted people. Challenges and difficulties apply to most of their activities. Traveling without vision is challenging for the congenital blind, adventitious blind, and even blindfolded sighted people (Picinali, Afonso, Denis, & Katz, 2014). Therefore, an orientation and mobility (O&M) program was created for visually impaired people, teaching safe, efficient, and effective travel skills, including how to use common tools, for example, white cane and sensory compensation (Vecchi & Cattaneo, 2011) to sense their surrounding environment as an important part of forming a mental map. Independently walking through cities or buildings is still difficult as a number of problems are encountered, for example, obstacles, noise, and other barriers which directly affect their daily activities and navigation (Williams, Galbraith, Kane, & Hurst, 2014; Williams, Hurst, & Kane, 2013; Zeng, 2015).

Visually impaired people have more confidence traveling (outdoors and indoors) with the white cane (Williams et al., 2013; Williams et al., 2014), which increases their perception and familiarity of spaces through the environment cues (e.g., landmarks) they receive when the cane hits something. Traveling inside buildings creates other difficulties as visually impaired people cannot sense and use landmarks to help move around spaces: especially walking through unfamiliar, crowded, and wide-open spaces due to limitations of their sensing environmental cues (light, smell, and noise) (Vecchi & Cattaneo, 2011) and randomly placed obstacles. As a result, visually impaired people may take a long time to familiarize themselves with spaces and to construct a mental map.

When traveling indoors, most of the outdoor challenges are not present, but head-level and trip accidents and even movable objects are still taken into consideration. Learning a new environment like a hospital, mall, or large complex building leads to navigation difficulty due to lack of accessibility information and environment cues (Williams et al., 2013). It is very hard to decide which way to reach the destination in such a complex crowded environment (Ganz et al., 2012). A guide dog would be a reasonable choice, but sometimes this is not permitted, for example, in hospitals (Guidedogs.org.uk, 2016), theaters, and zoos (Guidedogs.org.au, 2016). In the case of visiting an unfamiliar place, the guide dog needs to be trained beforehand so that it becomes familiar with the environment and remembers a standard or appropriate route (Kulyukin, Gharpure, Nicholson, & Pavithran, 2004).

Some visually impaired people use a variety of accessible maps (e.g., tactile maps) to help navigating indoors and learning the environment beforehand, while others use other assistive technologies, for example, indoor navigation system, wearable computing devices, and mobile devices. Accessible maps play a significant role in improving and accelerating the process of constructing mental maps (Almeida, Martins, & Lim, 2013; Schinazi, Thrash, & Chebat, 2016), whereas using tactile maps is difficult when the person is not familiar with raised surfaces and tactile representations (e.g., lines, graphs, and Braille) (see section "Use of assistance"), which takes a lot of effort to learn (\hAlmeida et al., 2013). Information provided in tactile maps is not sufficient in regard to safety, wayfinding, and orientation during navigation indoors (Papadopoulos et al., 2016).

Learning behaviors and challenges visually impaired people found during navigation indoors is essential for design of technologies, which enable independent-indoor navigation in unfamiliar spaces. The aim of this study is to get in-depth understanding of behaviors and strategies by visually impaired people, and investigate challenges found while navigating inside spaces. The study findings are analyzed and classified into five categories: (1) use of assistance, (2) distance estimation, (3) wayfinding and orientation, (4) unfamiliar spaces, and (5) obstacle and hazards.

Method

The purpose of this study was to acquire an in-depth understanding of the indoor navigation behaviors and strategies used by visually impaired people when walking inside buildings full of unfamiliar features. The environment perception of visually impaired people varies, depending on a person's characteristics (\hAlmeida et al., 2013) such as age, cognitive development, type of blindness (congenital or adventitious), and level of blindness. In this study, 45 participants were recruited and split into 30 visually impaired people and 15 sighted people.

Among the 30 visually impaired people recruited, 10 from the United Kingdom and 20 were from Thailand, randomly chosen with evenly distributed numbers of males and females. In all, 10 participants self-reported as congenitally blind, whereas 20 participants were adventitious blind; 22 participants self-reported as severely sight impaired (blind), while 8 participants were sight impaired (partially sighted). The sighted participants were (1) chaperones and O&M instructors and (2) developers and researchers from technical fields: human–computer interaction, accessibility, assistive technology, and interior design for elderly and disabled people.

Both the groups completed questionnaires: 18 questions (10 closed and 8 open) were listed for visually impaired people, while 18 questions (9 closed and 8 open) were used for sighted people. All the questions were split into five categories regarding indoor navigation by people with visual impairment (see Appendix 1). Semi-structured interviews were conducted for people with visual impairment, however, the findings from both the groups were used in terms of complementarity, clarity, and elaboration of the findings.

Findings

Analysis of the findings classified into five sections showed that visually impaired people experienced a lot of problems while navigating inside buildings and public spaces, for example, in universities, hospitals, malls, museums, and airports.

- Section "Use of assistance" describes the common tools that visually impaired people use, including restrictions of the use of assistance in particular places.
- Section "Distance estimation" discusses how visually impaired people estimate distance in unfamiliar spaces.
- Section "Wayfinding and orientation when travelling in unfamiliar spaces" describes wayfinding strategies and how people find their orientation in unfamiliar spaces.
- Section "Unfamiliar spaces" discusses problems and challenges found in public spaces, including four other types of buildings that were consequently found during the interviews.
- Section "Obstacles and hazards in indoor navigation" discusses obstacles and hazards discovered while navigating indoors.

Use of assistance

Participants were asked if they had received Orientation and Mobility (O&M) training or not, and what types of assistance they use for daily activities. A total of 19 participants (63%) indicated that they received training, while 11 (34%) did not, giving reasons such as another physical challenge and age-affect learning ability. Figure 1 shows the types and frequency of assistance used to navigate indoor spaces. Based on these numbers, the various assistance was ranked using the Borda Scoring Rule (BSR) (Shoham & Leyton-Brown, 2008); see Table 1. Consequently, the white cane and a sighted guide are the most promising assistance used to perform daily activities,

with the preference for a sighted guide as the first choice, while the white cane is used once people are familiarized with spaces and buildings by repeatedly visiting there a number of times. This contradicts the common belief of sighted people that the white cane is the preferred method of traveling; the data show that people use a mixture of methods when navigating in unfamiliar spaces and buildings.

People with visual impairment suggested some challenges the white cane cannot overcome, such as detecting slippery floor caused by water or fabric dropped on the floor, as well as body-level and head-level obstacles they run into inside buildings. In some buildings, stepping down from a change in level to circulations (e.g., corridor and pathway) is especially challenging, as they could collide with some head-level obstacle. As a result, a sighted guide is the most popular assistance ahead of a white cane, while a guide dog and tactile map were not chosen for the following reasons.

A guide dog is not affordable as it costs up to £27,300 for the special training until it is ready for people with visual impairment (Guidedogs.org.uk, 2016), and Thailand has no guide dog training center. However, to use a guide dog in unfamiliar spaces, it needs to be trained beforehand to memorize the standard and safe route, which usually takes 2–3 times or more of walking through the building until it can remember the route. This can be undertaken by the guide dog trainers, but one participant said that a guide dog is not permitted in Islamic religious spaces, because the dog is used for hunting and not as a pet or helper.

Likewise, a tactile map is not widely used, as it is not so easy to use and interpret its contents. Most said that the tactile map required a lot of effort to understand the contents provided; four (13%) participants had used a tactile map to find their way to a destination, two participants had successfully reached their destination, while the other two did not as the content provided was confusing and non-standard, which led to miscalculating the distance.

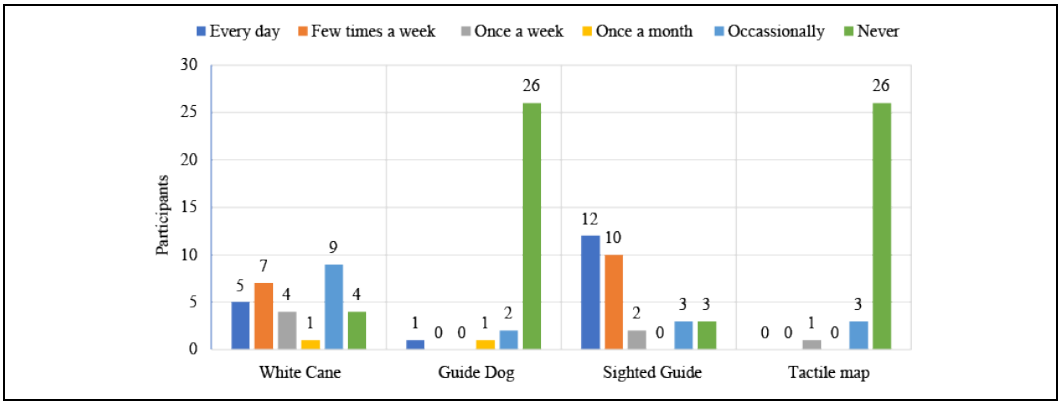

Figure 1. Survey of use of assistance.

Table 1. Assistance ranking: Different perspectives between visually impaired versus sighted people using Borda Scoring Rule (BSR).

Type of assistance	Visually impaired people		Sighted people	
	BSR	Ranking	BSR	Ranking
Sighted guide	109	1	49	2
White cane	76	2	63	1
Tactile map	9	3	13	3
Guide dog	6	4	13	3

Distance estimation

Many strategies have been used in distance estimation in both familiar and unfamiliar spaces (see Figure 2). There are different points of view between people with visual impairment and sighted people. The sighted suggested walking in the unfamiliar spaces, while people with visual impairment do not know the features inside the spaces, so a strategy of counting footsteps is appropriate instead of the use of landmarks as one of a combination of strategies. On the other hand, people with visual impairment argued that counting footsteps is sometimes difficult and takes a lot of mental effort and is easily distracted if walking into obstacles (e.g., furniture and landmarks), or into people, especially in unfamiliar crowded and noisy spaces and noise. As a matter of fact, about half of participants relied on their sense and feeling, focusing on the use of environment information to estimate distance, for example, smell, light, floor texture, and landmarks. However, not all of the participants could estimate the distance, especially those born blind and had never seen the world.

Wayfinding and orientation when traveling in unfamiliar spaces

Most navigation problems in unfamiliar spaces resolve into three challenges: find the current location, find the way to a destination, and find and maintain orientation. This indicates what kind of information people are looking for when entering unfamiliar spaces.

The findings from the survey of visually impaired people in Figure 3 suggests that visually impaired people first need a sighted guide in order to learn and familiarize themselves with unfamiliar spaces, rather than using landmarks to find a location and orientation themselves. Once they have learned the spaces, they will use sense and feeling (e.g., landmarks and environment information) to navigate themselves.

For finding the current location, participants usually estimate where they are from three different sources: 34% sighted guide, 30% landmarks, and 24% environment cues (light, noise, and odor), while using a smartphone is rare due to its limitation and accuracy of estimating location indoors. To navigate to the destination, people asked a sighted guide to take them there, or asked for instructions and walked themselves using three simultaneous clues: floor texture, environment cues, and landmarks.

For orientation, visually impaired people usually get confused by asking local people or a sighted guide. As they are unfamiliar with the space, visually impaired people are not able to use any source of information in the area, for example, landmarks on which the sighted usually rely, in order to estimate their location and orientation. One participant said that to find his orientation while navigating in his home, he had drawn an image of the relationships between each landmark and other landmarks, while another participant employed echolocation in wayfinding to detect her orientation.

Unfamiliar spaces

This section discusses the level of difficulty of, and the level of confidence required in, unfamiliar spaces, for example, in a university, hospital, department store, museum, and airport. The findings show that most participants (up to 70%) have not usually visited such venues due to the physical challenges, where they need assistance from a sighted guide or a local person. Most participants agreed that navigating inside the buildings listed in Figure 4 is too difficult by themselves for the following reasons.

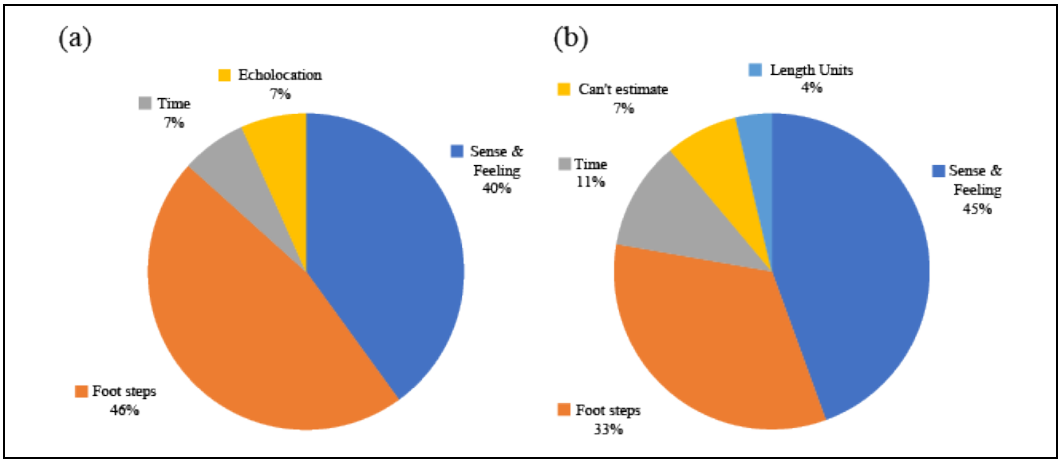

Figure 2. Distance estimation survey. (a) Visually impaired people. (b) Sighted people.

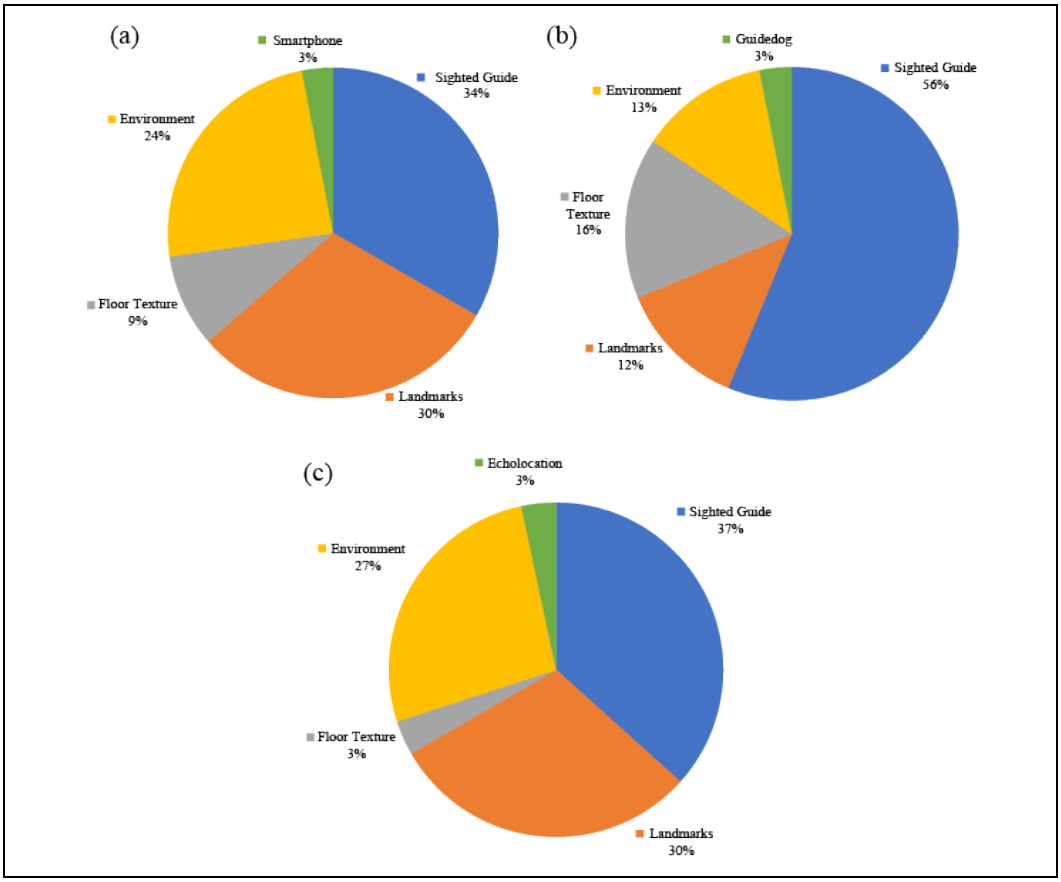

Figure 3. Wayfinding and orientation survey. (a) Find current location. (b) Find way to destination. (c) Find orientation.

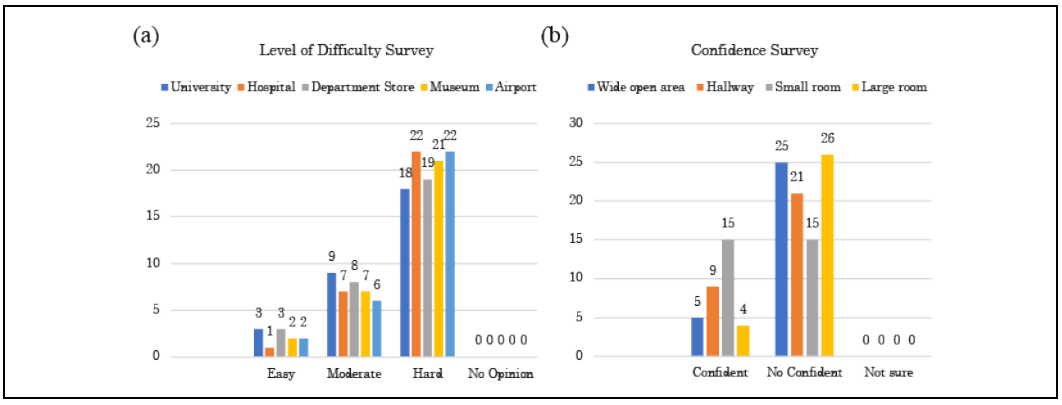

Figure 4. Unfamiliar spaces survey. (a) Level of difficulty. (b) Confidence.

Universities, colleges	Complex and medium to large buildings. Most participants aged between 18 and 29 said that navigating within buildings of colleges and universities is either medium or hard, depending on the size of population inside the buildings, and type of building. For example, engineering buildings are usually complex and have a lot of engineering equipment and furniture, which are usually relocatable and able to cause them harm.
Hospitals, public healthcare	Busy, noisy, complex and large-sized buildings. Up to 22 of participants (73%) agreed walking inside a hospital is very difficult due to population size of patients, nurses, doctors, and visitors, and a lot of obstacles, for example, hospital beds and furniture. Most participants were distracted by the noise and the many obstacles surrounding them, which therefore made them lose their way, and also lose orientation as they cannot use any landmark and environment information.
Shopping malls, department stores, supermarkets	*Shopping mall*: busy, large, wide-open and crowded buildings. *Department store*: busy, large, but well-organized buildings. *Supermarket*: small to medium buildings Although the buildings are well-structured, participants still found it difficult to walk by themselves. A total of 18 (60%) agreed shopping is challenging due to obstacles, for example, people and trolleys, and problems in reading information, such as price and product name. Most shops do not provide any accessibility information on the label of the products, for example, Braille or audio feedback, but some, like medicine, are embossed with Braille. This is useful, but Braille cannot be put on every package due to its limitation and cost. As a result, visually impaired people cannot find what they are looking for.
Museums, exhibitions	Complex, well-organized and medium to large buildings. This type of building is usually full of exhibitions, for example, antique statues or paintings, which are valuable. A total of 22 of the participants (73%) said that they need to be careful when walking inside this type of building as they could damage the exhibits. The signage cannot be seen or read. To prevent physical contact, most buildings usually set up a colored line (on the floor) or a rope to indicate that the area behind the line is prohibited. This can be a problem since visually impaired cannot see the line when walking in a museum. Participants suggested a rope, edge, and handrail are useful, possibly, illuminated which provides good contrast for partially sighted people.
Airports	Busy, noisy, complex, and large buildings. Some areas are wide open. These buildings are typically large and full of people walking around, and airport furniture, for example, check-in counters and seating, which are all counted as

	obstacles. Most participants (73%) said walking inside an airport alone is very difficult, since they often bump into people. Noise is also an obstacle, making them lose their orientation. Walking in the wide-open areas is still difficult as it makes it easier to get lost, as they cannot find landmarks in the noisy and busy environment. To reach the Gate is still difficult due the complexity of the buildings and long distances they need to walk, although they can request support services. Furthermore, escalators must be used, which most people with visual impairment are afraid of because they do not know where the steps are, and the edge of the steps is not high contrast, which is dangerous if they trip and fall.

Considering these five types of building, there are four types of spaces inside the building and public space whose difficulty in navigating need to be considered separately: wide-open area, hallway, small room, and large room. From the survey, 21–26 participants (70%–87%) said they were not confident in navigating through wide-open areas, hallways, and large rooms, as it is too difficult to navigate independently. Most participants got lost usually while just standing or navigating through wide-open areas. Most said that there were not many landmarks they could use to help them detect their orientation, such as wall, door, curb, edge, and surface. With noise and people walking about, a lot of distractions to visually impaired people are created.

Large rooms refer to auditoriums, stadiums, concerts, theaters, and halls. Up to 26 participants (87%) said that large rooms are usually full of (auditorium) chairs and tables, and hallways are too wide to navigate by themselves. The problem is that, when they do attend events, for example, concerts, movie theaters, or conferences, they could not find their seat as it has no Braille indication. As with stairs where tread depth and rise height are not standard, the dimension of chairs is not standard or the offset space between each row in the seating area.

For hallways and corridors, some of the participants are confident (30%) in navigating them, while others are not (70%), because some hallways and corridors are too wide, and that makes them afraid of walking alone. When they tried to walk along the wall, there was furniture installed in the space, and obstacles attached on the wall, but too high to be detected by white cane, for example, wall-mounted telephone and fire extinguisher. Two participants suggested that some visually impaired people have used the edge of a door to detect their orientation in order to find their way. However, this edge is usually sharp and sometimes harm people encountering it.

For the small rooms, half of the participants said that they had a lot of confidence, as they can find landmarks easier than other types of space, even though the settings are changing all the time. The other half countered that it is still difficult to navigate these spaces if they are not familiar with them. This situation is similar to walking in museums. They are afraid that they could damage things inside the room.

In addition to unfamiliar spaces, however, the findings also suggested a further four types of buildings that are usually visited for daily activities: train stations, libraries, canteens/cafeterias, and auditoriums/halls.

Train stations	Noisy, busy, small to medium buildings, and dangerous spaces. The first is noise that distracts them a lot while they attempt to find their orientation and gather train information. In this type of building, it is hard to find a landmark where a crowd of people gather in the daytime. The second problem is the gap between the trains and the platforms. All the partially sighted participants said that they are afraid of stepping up to the train because they cannot find the edge, even though it is usually indicated in yellow color with high contrast.
Libraries	Well-organized, busy, and small to medium buildings, but too silent. This type of building is usually silent and full of furniture, for example, chairs, tables, and bookshelves, but well-organized. Most partially sighted participants said that it

	is very difficult to find a book by themselves due to blurry vision, which requires using a magnifying glass or device in order to identify the name of the book. Most books do not have Braille embossed on their covers. Looking for books on your own becomes impossible. Likewise, all the partially sighted participants said that some libraries have automatic sliding door systems installed at the entrance or elsewhere. This type of door usually has no warning signs saying that it is glass and transparent. This could be a problem to people who are partially sighted, because they cannot distinguish between the door and an empty space. Some buildings, on the other hand, have placed glass manifestation (e.g., markings and motifs) on the doors, but they can hardly be seen because they are not sufficiently high contrast. In addition, this type of door sometimes does not work due to some technical difficulty, for example, sensors or mechanical issues, and could harm its users.
Canteens, cafeteria	Canteens and cafeterias are usually filled with tables and chairs which can be relocatable within the space. This problem sometimes affects visually impaired when visiting, depending on the number of people in the area. For example, lunch time at the universities and shopping centers are usually filled with crowds and noise.
Auditoriums, stadiums, concerts, theaters, halls	Busy, large buildings. Walking inside this type of building is sometimes difficult, depending on situations, events, and number of people. One participant said that it was very hard, when she attended the concert, to find her seat even though accompanied by friends. Also, this type of building often does not usually provide any labeling and accessibility for disabled people.

Obstacles and hazards in indoor navigation

Obstacles and barriers are something that people with visual impairment face every day. As seen in Figure 5, most participants reported being hit by obstacles that can cause them to lose their body-balance and orientation, which is most important while navigating. In this section, the findings show how often most visually impaired people experienced hitting various obstacles.

It is clear that noise is the most impact factor they face, while silence is the least. In a wide-open area, too much noise creates a lot of distraction, resulting in loss of orientation. This situation usually happens when the space is full of crowds, for example, wide-open area in a department store. On the other hand, a too quiet space tends to create panic in people with visual impairment, as they receive no feedback, and they think that the direction they are walking in is wrong. This situation is serious; people may end up injured if they are walking inside a building where some area is being renovated, and warning notices are not provided.

Most participants said that the majority of obstacles they hit are at body-level and head-level, for example, wall-mounted furniture and objects, and hanging labels, as they cannot detect them with a white cane or a guide dog, which are only able to detect ground-level obstacles. In addition, the white cane cannot detect some slippery floor hazards, especially a wet floor or objects that make the floor more slippery when dropped on the floor, for example, fabric. However, moving obstacles, for example, people and trolleys were also mentioned as the obstacles that up to 70% of people with visual impairment face.

This study also found that light is useful and important to partially sighted people. People have used light as a helper to detect distance and orientation while navigating inside buildings. However, in some areas, if the light is too bright and illuminates the eyes, it causes temporary blindness.

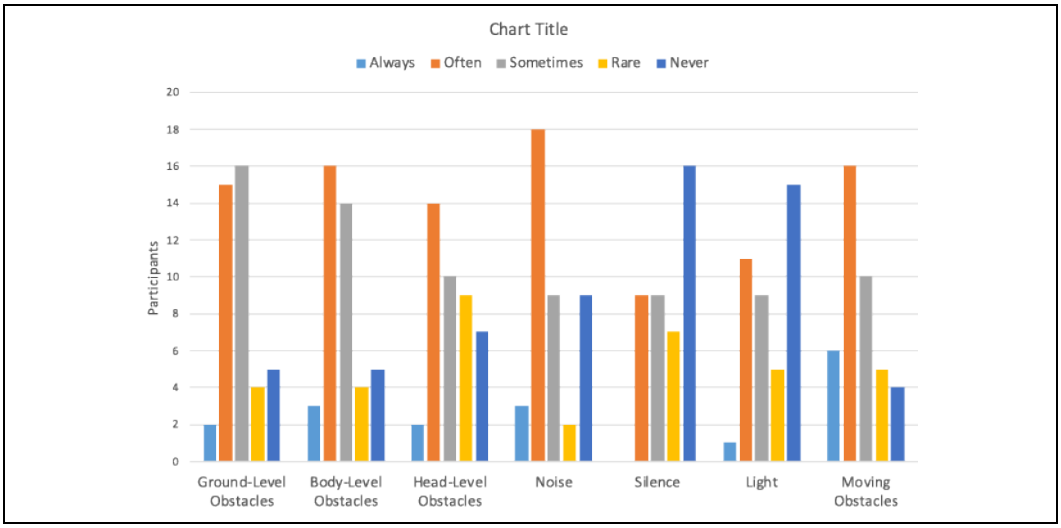

Figure 5. Obstacles experience survey.

Discussion

In this study, 45 people (30 people with visual impaired, and 15 sighted people) were interviewed using a questionnaire with five categories (18 questions, see Appendix 1). This resulted in 45 hr of audio recording which gave a rich set of data for analysis. The finding of this study is important, as there is no previous study on indoor navigation behavior by blind people in unfamiliar spaces and buildings. Thus, the findings of this study will be particularly important for building and interior designers to make a better and friendly environment for people with visual impairment. Moreover, the findings can be useful for O&M instructors and specialists to improve O&M courses and training, and of course researchers who work in the field of assistive technology for better indoor navigation for blind people.

The findings of our study indicated that visually impaired people experienced challenges when walking inside unfamiliar spaces, where a common tool like the white cane cannot help them navigate independently. Most of the participants cannot navigate in such spaces in their first attempt. Therefore, they need to be accompanied by a sighed guide, in order to learn and familiarize themselves with the space before independent navigation with a white cane or other assistance.

While visually impaired people have used the sense and feeling instead of counting footsteps to find their location and orientation, the findings suggest that employing a combination of strategies for navigation instead of using one particular strategy creates confidence in navigation in familiar spaces. For example, one participant had simultaneously used their sense and feeling while counting footsteps during indoor navigation. Another used a timing strategy together with their sense and feeling. For unfamiliar spaces, however, people with visual impairment usually rely on a sighted guide and landmark and environment information.

Conclusion

In the outdoors, visually impaired people can sense and use environmental cues using the white cane, while inside public spaces, many of the environmental cues cannot be used due to various difficulties. Technologies are being invented to solve the navigation problems of people with

visual impairment. To help the visually impaired to have freedom in navigation, additional information (obstacles, barriers, and accessibility) is essential to be introduced, which led to this study.

The findings revealed that navigating inside buildings and public spaces full of unfamiliar features is too difficult to attempt the first time for a number of reasons, reducing confidence in independent navigation. Navigation inside buildings by the visually impaired is a challenge, as it takes a long time to become familiar with spaces, which leads to the need for sighted people's assistance; there is also a problem regarding distance estimation and instruction to the destination.

Many difficulties are experienced by the visually impaired while inside public spaces full of unfamiliar features, such as obstacles, barriers, and accessibility information that have made them unable to navigate safely. To overcome this, the use of indoor landmarks was found to be significantly useful to them. Not only landmarks, but environment cues (e.g., light, smell, and noise) are also used in the wayfinding and mental map construction processes.

The findings of this study investigated the problems and challenges experienced by visually impaired people during indoor navigation, and what kind of behaviors and strategies that they use to overcome their problems. The findings can be useful for further developments, such as indoor navigation systems, wearable computing devices, and mobile devices as well as for O&M specialists and instructors, in constructing a spatial representation (Jeamwatthanachai, Wald, & Wills, 2017).

Funding

The author(s) received no financial support for the research, authorship, and/or publication of this article.

ORCID iD

Watthanasak Jeamwatthanachai https://orcid.org/0000-0002-4622-0493

References

Almeida, X. M., Martins, L. B., & Lima, F. J. (2015). Analysis of wayfinding strategies of blind people using tactile maps. *Procedia Manufacturing, 3*, 6020–6027.

Ganz, A., Schafer, J., Gandhi, S., Puleo, E., Wilson, C., & Robertson, M. (2012). PERCEPT indoor navigation system for the blind and visually impaired: architecture and experimentation. *International Journal of Telemedicine and Applications, 2012*, 894869.

Guidedogs.org.au. (2016). Frequently asked questions. *GuideDogs SA/NT*. Retrieved from https://www.guidedogs.org.au/frequently-asked-questions (accessed May 5, 2016).

Guidedogs.org.uk. (2016). Are dogs allowed everywhere? Access all areas. *Guide Dogs*. https://www.guidedogs.org.uk/how-you-can-help/campaigning/access-all-areas/ (accessed May 5, 2016).

Jeamwatthanachai, W., Wald, M., & Wills, G. (2017). Map data representation for indoor navigation by blind people. *International Journal of Chaotic Computing, 4*, 70–78.

Kulyukin, V., Gharpure, C., Nicholson, J., & Pavithran, S. (2004, September 28–October 2). *RFID in robot-assisted indoor navigation for the visually impaired*. Paper presented at Proceedings of 2004 IEEE/RSJ International Conference on Intelligent Robots and Systems, (IROS 2004), Sendai, Japan.

Li, K. J., & Lee, J. (2010, October 18–22). *Indoor spatial awareness initiative and standard for indoor spatial data*. Paper presented at Proceedings of IROS 2010 Workshop on Standardization for Service Robot, Taipei, Taiwan.

Papadopoulos, K., Charitakis, K., Kartasidou, L., Kouroupetroglou, G., Gumus, S. S., Stylianidis, E., . . . Lithoxopoulos, N. (2016). User requirements regarding information included in audio-tactile maps for individuals with blindness. In *International conference on computers helping people with special needs* (pp. 168–175). London, England: Springer.

Picinali, L., Afonso, A., Denis, M., & Katz, B. F. (2014). Exploration of architectural spaces by blind people using auditory virtual reality for the construction of spatial knowledge. *International Journal of Human-Computer Studies, 72*, 393–407.

Schinazi, V. R., Thrash, T., & Chebat, D. R. (2016). Spatial navigation by congenitally blind individuals. *Wiley Interdisciplinary Reviews: Cognitive Science, 7*, 37–58.

Shoham, Y., & Leyton-Brown, K. (2008). *Multiagent systems: Algorithmic, game-theoretic, and logical foundations*. New York, NY: Cambridge University Press.

Williams, M. A., Galbraith, C., Kane, S. K., & Hurst, A. (2014). "Just let the cane hit it": How the blind and sighted see navigation differently. In *Proceedings of the 16th international ACM SIGACCESS conference on computers and accessibility* (pp. 217–224). New York, NY: ACM.

Williams, M. A., Hurst, A., & Kane, S. K. (2013). "Pray before you step out": Describing personal and situational blind navigation behaviors. In *Proceedings of the 15th international ACM SIGACCESS conference on computers and accessibility* (p. 28). New York, NY: ACM.

Vecchi, T. & Cattaneo, Z. (2011). *Blind vision: The neuroscience of visual impairment*. Cambridge, MA: The MIT Press.

World Health Organization. (2014). *Visual impairment and blindness*. Retrieved from http://www.who.int/mediacentre/factsheets/fs282/en/ (accessed May 16, 2016).

Zeng, L. (2015). A survey: Outdoor mobility experiences by the visually impaired. In A. Weisbecker, M. Burmester, & A. Schmidt (Eds.), *Mensch und Computer 2015—Workshopband* (pp. 391–397). Berlin, Germany: De Gruyter Oldenbourg.

Appendix 1

#	Section	People with visual impairment	Sighted people
01	Use of assistance	Did you attend a mobility training course, for example, orientation and mobility?	Is a mobility training course (e.g., orientation and mobility) important to visually impaired and blind people?
02		Which assistance do you use when you navigate inside buildings by yourself? How often do you use the assistance for your daily routines?	Which assistance do visually impaired and blind people use when navigating inside buildings by themselves? How often do visually impaired people use this assistance?
03	Distance estimation	How do you estimate the distance while navigating inside buildings by yourself?	How do visually impaired and blind people estimate the distance while navigating inside buildings by themselves?
04	Wayfinding and orientation when traveling in unfamiliar space/unfamiliar	How often do you navigate by yourself inside unfamiliar spaces, for example, university, hospital, department store, museum, and airport?	How often do visually impaired and blind people navigate by themselves inside unfamiliar spaces, for example, university, hospital, department store, museum, and airport?
05	spaces	What is the level of difficulty to navigate in university, hospital, department store, museum, and airport?	While navigating inside buildings by visually impaired and blind people, what is the level of difficulty to navigate in university, hospital, department store, museum, and airport?
06		Do you have confidence to navigate inside buildings by yourself through wide-open, hallway, room, large room?	Do visually impaired and blind people have confidence to navigate by themselves through wide-open, hallway, room, large room?
07		Inside unfamiliar spaces inside buildings, how do you know where you are?	In unfamiliar spaces inside buildings, how do visually impaired and blind people know where they are?
08		Inside unfamiliar spaces inside buildings, how do you reach your destination?	Inside unfamiliar spaces inside buildings, how do visually impaired and blind people reach your destination?
09		How can you find your orientation or the direction you are heading to?	How can you find your orientation or the direction visually impaired and blind people are heading to?
10		What landmarks are you looking for in order to learn or to help you to navigate by yourself through unfamiliar spaces?	What landmarks are visually impaired and blind people looking for in order to learn or to help you to navigate by yourself through unfamiliar spaces?

11		Have you ever asked anybody (e.g., reception and local people) for directions or instructions to reach the destination?	
12		Have you ever found any directions or instructions from local people has been confusing or ambiguous?	Have visually impaired and blind people ever found that directions or instructions from local people have been confusing or ambiguous?
13	Obstacles and hazards in indoor navigation	Have you experienced any problems or challenges while navigating by yourself inside buildings? For example, ground/body/head-level obstacles, noise, silent, or light.	Have visually impaired and blind people experienced any problems or challenges while navigating inside buildings? For example, ground/body/head-level obstacles, noise, silent, or light.
14		By navigating inside buildings by yourself, have you ever experienced hitting or being hit by the following obstacles?	When navigating unfamiliar spaces inside buildings, do visually impaired and blind people experience a collision by the following obstacles?
15		What obstacles can you detect by your assistance (e.g., white cane, guide dog, tactile map)?	What obstacles can visually impaired people detect by their assistance (e.g., white cane, guide dog, tactile map)?
16		What obstacles are you not able to detect by your assistance (e.g., white cane, guide dog, tactile map)?	What obstacles are visually impaired people not able to detect by their assistance (e.g., white cane, guide dog, tactile map)?
17		While navigating inside buildings, how do you sense or know any dangers in your way?	How do visually impaired people perceive any dangers in their way while navigating inside buildings?
18		Have you ever found that using stairs, escalators, or elevators is difficult and dangerous?	Have visually impaired people ever found that using stairs, escalators, or elevators is difficult and dangerous?