# Listening to the Voice of People with Vision Impairment

## Revealing Outdoor Mobility Traits for Improved Assistive Technologies

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***Abstract*—Extensive research developed assistive technologies (ATs) to improve mobility for people with vision impairment (PVI). However, a limited number of PVI rely on ATs for mobility. One of the factors contributing to the limited reliability and low acceptance of ATs is the developers' failure to consider PVI mobility traits from the target group's perspective. Many developers and researchers proposed solutions based on their knowledge and experiences, where PVI have been excluded from several studies except for limited involvement in testing phases. Accordingly, this study aims to bridge this gap by providing comprehensive information on PVIs' behaviors, challenges, and requirements for safe and independent outdoor mobility. Therefore, a total of 15 participants with vision impairment were involved in semi-structured interviews and two observation sessions. One key finding highlights the need for AT that complements the conventional cane and overcomes its limitations, not substituting the cane. Moreover, the proposed AT should address instant mobility and future needs simultaneously. Overall, the study contributes to providing comprehensive knowledge on PVI safe and independent mobility traits, which assist AT developers to explore the potential barriers and facilitators of the adoption of ATs among PVIs and leads to develop effective and reliable ATs that meet their needs. For future work, the researchers will develop an AT that complements the conventional cane, supports instant mobility, and enhances cognitive map formation.**

***Keywords*—People with vision impairment; assistive technology; outdoor mobility; behaviors; challenges; requirements**

## I. Introduction

Outdoor mobility is one of the significant challenges for people with vision impairment (PVI), especially in an unfamiliar environment. Globally, PVI still rely on the white cane and guide dog for primary mobility [1]. The white cane gained widespread attention due to its robustness, object detection effectiveness, simplicity, low cost, lightweight, and portability. Nevertheless, the limitation of the cane is the inability to provide full safe mobility. For example, the cane lacks the capacity to detect chest or head-level obstacles [1], small obstacles and various terrain types [2]. Besides, cane techniques require a long training period to be well-understood [1]. The provision of complete safe mobility remains challenging when using a guided dog with limitations in dog cost, speed and path directions [3].

Based on the limitations of conventional mobility aids (white cane and guide dog), high-performance technologies have dominated interest from various disciplines to develop ATs to support mobility for PVI [4], [5]. Although several proposed systems reported high performance and achieved their goals, only a few ATs have been accepted and considered reliable by the end-users [6], [7]. A significant contributing factor to the low acceptance of proposed ATs is the lack of understanding of the target group's requirements. Several researchers [8], [9] developed ATs based on their knowledge and experience without engaging the target group in any design phase. However, this exclusion of PVI from the research has resulted in a poor understanding of the PVI needs [10] and negatively impact the acceptance and success of the proposed AT [11]. The challenges in recruiting people with disabilities are the reason for this avoidance, as [12] stated. These challenges include logistic problems, participants' safety, and study duration.

In contrast, involving the target group in the design phases of ATs provides the developers with a comprehension of PVIs' preferences, lifestyles, challenges, and requirements [3], [13], [7]. This knowledge plays a vital role to develop more effective ATs. For this reason, the study aims to answer two primary research questions: 1) what are the prevailing mobility behaviors and challenges encountered by PVI? and 2) What are the ATs' characteristics that potentially can address these challenges and fulfill PVI ambitions?

To achieve this goal, a qualitative study was conducted involving 15 participants from the PVI community. Three sessions were performed, face-to-face interviews, observation in a familiar environment, and observation in an unfamiliar environment. Participants shared their mobility practice, challenges, and narrated personal stories and ambitions for the future ATs. The study approach of involving PVI participants with three different instruments adds to the study's novelty, where the study provided insights into PVI's lived experiences that are often missing in other studies.

This study manly highlights extensive illustration of mobility behaviors applied by the PVI to achieve safe outdoor mobility. Additionally, the significant challenges associated with outdoor mobility from the PVI perspective. Moreover, provides recommendations for ATs developers about the features of novel ATs that may satisfy the requirements and expectations of PVI to enhance outdoor safe mobility.

The subsequent aspects of this article are organized as follows: Section II presents a literature review of studies on PVI's mobility traits, challenges, and features inherent in existing solutions. The methodology employed is highlighted in Section III whereas Section IV presents the findings. Next, the discussion and recommendation of the study are outlined in Section V and a brief conclusion was presented in Section VI.

## II. Related Work

A substantial amount of literature exists on mobility for PVI from target groups' perspectives. The main focus in the published studies includes the PVI behaviors for outdoor mobility, the challenges faced, requirements, and expectations of the solution that may improve their safe mobility. Although most past studies reported one or two mobility aspects, this study attempts to aggregate the whole mobility context and reveal new details expressed by PVI expressed via verbal and non-verbal behaviors.

The researchers in [7] conducted a User-Centered Design (UCD) study to specify the PVI requirements of an AT for outdoor navigation in the cultural environment. The study that involved PVI and sighted participants determined several functionality, design, and operational features of the ATs. Some findings revealed the need for GPS, obstacle avoidance, network aspects, video streaming, and vocal feedback. The researchers developed an initial prototype AT based on the findings. However, they reported that a lot of work is needed to fulfill the PVI ambitions especially from the design and functionality aspects. One study limitation is even though the study applied interviews and questionnaire instruments; PVI was involved in the questionnaire only, and the interview sessions were with stakeholders. Additionally, the findings revealed the ATs features that support mobility but it lacks the behaviors and challenges that the target group face.

The study of [14] aimed to highlighting the navigation behaviors and challenges for PVI. A total of 30 participants were interviewed through phone calls. Based on the key findings, the researchers reported that mastering orientation and mobility (O&M) skills were enough for navigation. Additionally, the white cane seeks for obstacles whereas the guide dog avoids obstructions. In terms of AT, the study found that there was no appropriate navigation technology for all PVI, rather it was based on individual needs and preferences. Factors involving high cost and complexities contributed to the absence of navigation technologies. One study limitation is the avoidance of ATs as supportive aids for PVI mobility.

In another related work, PVI-related environmental information for safe and independent commutes was investigated [15]. Semi-structured interviews were performed with 18 PVI participants. The main mobility behaviors reported in the study were asking people for help, using smell and auditory senses, assigning points of reference, and using sidewalk edges. In contrast, orientation and obstacles were demonstrated as the major challenges experienced during daily activities. Also, crossing the street was a significant risk faced by the PVI. The main obstacles impacting PVI's safety were potholes, sidewalk surface, windows and doors, pedestrians, and vendors. The public also had negative attitudes towards PVI. The study provided major challenges that PVI faces; however, it lacks the ATs features which can address these challenges and support safe mobility for PVI.

The study of [16] investigated how navigational technologies improved mobility for PVI. This qualitative research interviewed 23 participants with VI relying on the white cane, while seven of them also used a guided dog. All the participants used their smartphones to access navigation technology such as Google Maps, Apple Maps, Siri, and video calls. The key study finding suggested that safe mobility for PVI could be made more effective by combining conventional mobility aid represented by O&M skills with navigation technologies. Such aids detect the front area, and the navigation technology conveys information about the turn-by-turn route. Although the study demonstrated the importance of ATs in supporting mobility for PVI, it focused on the apps only.

Although navigation is an essential part of mobility, navigation technologies failed to consider the limitations of using conventional aids for detection, such as distinguishing small obstacles and obstacles higher than the ground level. Additionally, several researchers argued using a smartphone on-journey because it impacts on user's safety [11]. Besides, at least one hand should be free during the navigation [17] and users are concerned about battery drain for the whole trip [18].

Despite much research on mobility by involving a group of participants from the target community, several studies relied solely on interviews and excluded the real interactions with the environment. Only a few studies aggregated the mobility behaviors, challenges, requirements, and solution ambitions from PVI's viewpoints. In contrast, this study applied different instruments for data gathering; face-to-face interviews and two real-world observation sessions in familiar and unfamiliar environment, thus enabling the collection of verbal and non-verbal reactions. This study also combined the mobility context (behaviors, challenges, ambitions, and suggestions of the solution) from a diverse group of PVI.

## III. Methodology

This study employed qualitative methodologies for data collection and analysis. Ethical approval with reference number (JKEUPM-2019-463) was obtained from the Ethical Committee of the University of Putra Malaysia (UPM).

### *A. Participants*

A total of 15 adult participants with vision impairment comprising eight females and seven males were recruited. The mean age of the participants is 41 years and the standard deviation (SD) is 16.3. Among the participants, 11 were totally blind (B1) while the remaining four were partially blind (B2). Furthermore, six participants were congenitally blind, nine experienced gradual blindness occurring later in life, and none of the participants had other disabilities.

All participants relied on the white cane for mobility, 12 of them passed the O&M training course and the other three were in O&M training when this study was conducted. The manager of the Research and Development Department in the Malaysia Association for Blind (MAB) assisted in the recruitment process. The participants' demographic information is shown in Table I.

TABLE I. PARTICIPANT DEMOGRAPHIC INFORMATION

| Participant | Gender | Age Range | Blindness Level | Blindness Age | Activity [a] |
|---|---|---|---|---|---|
| P1 | F | 41-60 | B1 | Adulthood | Int, Ob1, Ob2 |
| P2 | F | 26-40 | B1 | Congenitally | Int, Ob1, Ob2 |
| P3 | F | 26-40 | B1 | Childhood | Int, Ob1, Ob2 |
| P4 | M | 26-40 | B1 | Adulthood | Int, Ob1, Ob2 |
| P5 | F | Above 60 | B1 | Adulthood | Int, Ob1, Ob2 |
| P6 | M | 26-40 | B2 | Congenitally | Int, Ob1, Ob2 |
| P7 | M | Above 60 | B1 | Congenitally | Int, Ob1, Ob2 |
| P8 | F | 26-40 | B1 | Congenitally | Int, Ob1, Ob2 |
| P9 | M | 18-25 | B2 | Adulthood | Int, Ob1, Ob2 |
| P10 | F | 26-40 | B1 | Childhood | Int, Ob1, Ob2 |
| P11 | F | 26-40 | B1 | Congenitally | Int, Ob1, Ob2 |
| P12 | M | 26-40 | B1 | Congenitally | Int, Ob1, Ob2 |
| P13 | M | 18-25 | B1 | Adulthood | Int |
| P14 | F | 41-60 | B2 | Adulthood | Int |
| P15 | M | 41-60 | B1 | Adulthood | Int |
| Overall | 8 F<br>7 M | Mean: 41 SD: 16.3 | 11 B1<br>4 B2 | 6 Congenitally<br>9 Later | |

[a.] Activity: Int: interview. Ob1: observation session in a familiar environment. Ob2: observation session in an unfamiliar environment

### *B. Instruments*

Data were collected via three sessions; a semi-structured interview, Session A and two outdoor observation sessions, Session B in a familiar environment and Session C in an unfamiliar environment. All participants were involved in the face-to-face semi-structured interview. Specifically, 12 participants engaged in the two observation sessions. As advised by the O&M instructor, three participants were excluded from the observation sessions as they lacked the ability to navigate independently and they were involved in O&M training when this study was conducted.

*1) Session A – semi-structured interview:* To elicit the mobility context for PVI, face-to-face individual interviews were conducted with the 15 participants taking between 35 to 60 minutes to be completed. The interview questions were structured into three categories; demographic information and visual impairment history, outdoor mobility behaviors and challenges, and knowledge/experience on mobility ATs. All sessions were video and audio recorded, and all verbal and non-verbal cues, such as emotional signs were collected.

*2) Session B – observation I:* The first observation session was in a familiar environment and the purposes were to verify that participants could navigate independently without being exposed to any risk in the unfamiliar environment. In addition, the session was performed to verify the interview responses and identify how the PVI interact with the elements of the familiar sites. These events are expected to reveal the mobility behaviors, especially the emotional indications. Other reasons for this session were to uncover the mobility challenges with the existence of the cognitive map and to compare the differences in mobility behaviors between the familiar and unfamiliar environments.

Each participant strolled with the white cane for about 10 minutes in the area surrounding MAB Brickfields; Kuala Lumpur, MAB buildings, and MAB courtyard. The site contains a flat area, pavements with tactile blocks, and several obstacles like trees, poles, staircases with handrails, streets, and traffic lights. The think-aloud protocol was applied, thereafter, the participants were asked to express their knowledge about environmental elements surrounding them. All the sessions were video recorded. Fig. 1 presents a sample of the familiar observation sessions.

*3) Session C – observation II:* The second observation session was in an unfamiliar environment. For safety purpose, a sighted individual walked close to the participant to intervene if required. Moreover, medical insurance was provided for each participant following the recommendation of the ethics committee.

The purposes of the unfamiliar observation session were to uncover PVI mobility behaviors and challenges during navigations, verify what the participants expressed in the interview, and identify the compatibility with environmental reactions [12]. In addition, this session was designed to gather the non-verbal cues, clues, and reactions that an individual with VI practices under real-world situations.

Each participant navigated in an unfamiliar environment for 15 to 20 minutes. The site used for the navigation exercise was in the UPM campus, besides the Sultan Salahuddin building and along a path of 250 to 300 meters as shown in Fig. 2(a) and

2(b) show unfamiliar observation site. This area was selected since all the participants were unfamiliar with the environment and controllable in terms of pedestrians, traffic, and obstacles. During the observation sessions, the think-aloud protocol was applied and the participants were asked to express their thought about everything they feel surrounding them. The sessions were also video recorded.

a) Area between MAB buildings b) Brickfields area surrounding to MAB

Fig. 1. Familiar observation sessions.

## C. Data Analysis

All audio and video files were transcribed and thematic analysis was applied to analyze the data. Thematic analysis was performed because of its flexibility and provision of rich, detailed, and well-structured results [19], [20]. The analysis yielded a total of 554 quotations, which were combined into 26, which were then filtered and combined into four themes including, 1) mobility behaviors, 2) mobility challenges, 3) mobility aids, and 4) AT-required features. Data management and analysis were carried out using the NVivo 12.0 software [21].

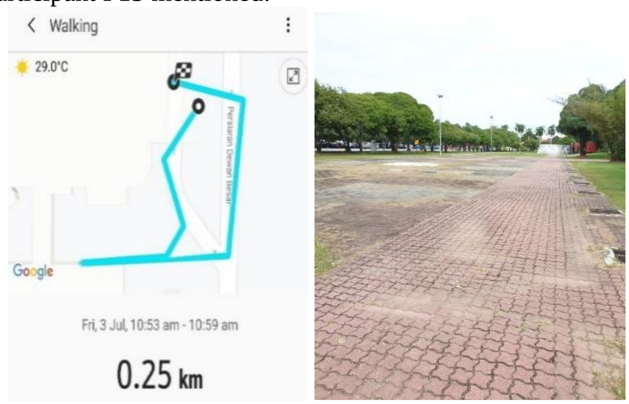
# IV. STUDY FINDINGS

Several studies demonstrated the mobility behaviors, challenges, and solutions PVI desired to enhance their outdoor mobility. However, this study demonstrated further insights into mobility traits that were expected and unexpected. This section describes the outcomes from the perspectives of PVI mobility behaviors and challenges, as well as their ambitions and preferences of the future mobility AT to support their safe mobility.

## A. Mobility Behaviors and Techniques

Spatial awareness is the PVI primary behavior in a familiar environment. In contrast, different techniques are performed to compensate for awareness in an unfamiliar environment.

*1) Cognitive map:* A cognitive map is a brain presentation of a spatial location [22]. It plays a main role in controlling the brain's navigation system [3]. Applying the cognitive map is the primary behavior associated with PVI mobility in a familiar environment, where PVI can visualize the surrounding area [23]. During the observation sessions in the familiar environment, all participants demonstrated high abilities to use the cognitive map for real-time awareness. For instance, they recognized the accurate location of different objects like poles, and staircases. By generating relationships between objects' positions, the participants were able to consider objects such as doors, drains, and floor texture changes as landmarks. Fig. 3(a), presents a participant indicating a door as a landmark. All participants explained their mobility abilities and independence in a familiar environment. For example, participant P13 mentioned:




a) Unfamiliar Observation Path b) Sample of Unfamiliar Observation Site

Fig. 2. Sample from the unfamiliar observation Site.

*"Outside with a white cane and without any help, needs to feel free … familiar place is easy."*

Moreover, a few participants do not use a white cane in familiar areas. For instance, participant P9 emphasized:

*"For a familiar place, I do not use the cane so much because I already have the cognitive map."*

The cognitive map reflected on the participants' mobility with confidence, comfort, pride, and independence. Participant P12 reported that he engages in social services to assist blind people in familiar places. Additionally, for a question about the number of visits needed to familiarize a place, nine participants responded that, after three to four visits with a companion, they familiarize the place, but it is difficult to familiarize complex structure areas.

*2) Techniques:* This study collected about 22 techniques performed by the PVI to navigate safely in both familiar and unfamiliar environments. However, all participants expressed their disappointment, fear, and anxiety when visiting an unfamiliar environment due to bad experiences. The primary technique used by all participants when visiting an unfamiliar place is accompanying a sighted individual. Most participants (n = 10) narrated their bad experiences in unfamiliar environments which involved falling, getting lost, traffic, and immoral attitudes of strangers. According to participant P1:

*"I don't like to fall… what I'll do if I'm lost? I will ask people, but you must be very careful asking people because people can even take you for a ride."*

Participant P15:

*"If unfamiliar (place), I think everybody does the same, go to an unfamiliar area with a person."*

The second-most used technique when visiting an unfamiliar place is *information collecting* as posited by 13 participants. Participants obtained relevant information about the site before embarking on the trip. The information includes the distance from a specific location to the destination, landmarks in route and the area, useable public transportation, and area accessibility for the PVI. Participant P15 declared as follows:

*"Normally I will ask my colleague and relatives. How does this place look like? So, they will tell me …. I try to imagine how it is."*

As well participant P11 mentioned:

*"I study the place before going. I get to know if I can take public transport and the accessibility of the place."*

Different sources of information were used including sighted individuals and software applications (e.g., Waze and Apple/Google Maps). Before the unfamiliar observation sessions, several participants asked about the site features. Furthermore, participants engaged in slow walking and wide floor sweeping of the cane in an attempt to carefully recognize the area surrounding their bodies. Also, they kept talking to the researcher to feel comfortable and safe.

The participants protect their face and head using their freehand as additional safety techniques for familiar obstacles above the ground. For the staircases, they relied on the handrail and check each stair's height by the cane and their foot before they step which is applied also for pavements and curbs. They relied on tactile paving, trailing along a wall, a sidewalk border, or a road's edge if it is available to keep walking in a straight line unless it is not practicable [3]. Fig. 3(b) presents a participant trailing a sidewalk edge. To cross the road, they rely on hearing sense. The participants evaluated the potholes and drains by checking the depth, diameter, and drain covered by the cane and then avoids it by jumping above the small ones, or moving to the left or right. For an obstacle, they touch it with the cane in an attempt to recognize its features before addressing the issue. In public places, they ask sighted people for help.

*3) Alerting the awareness:* During the unfamiliar observation sessions, when the participants contacted a barrier via the cane, they stopped or slowed down to the maximum, swept the cane on the floor widely, and carefully searched for any change or obstacle. When the individual recognized the situation, they performed an effective and correct action to tackle it. This experience demonstrated the necessity of providing PVI with spatial information before they face a new situation. Hence, no need to inform individuals about what to do or how to address the challenge. However, individuals flinched, stumbled, and were prone to fall when their body contacted with an obstacle before the cane. Moreover, most participants expressed their emotions according to the situation, such as anxiety, comfortable, fear, stress, and pride. P6 mentioned:

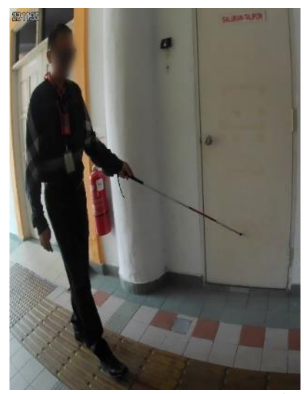
*"No, please no holes. Holes, especially holes, it is very difficult."*

Accordingly, AT developers should avoid informing the user.

What to do (e.g., "turn *left, go right"*), rather informing them about the obstacle within an appropriate time should be emphasized. Table II summarizes the mobility behaviors and techniques that PVI perform in the familiar and unfamiliar environments to protect their safety.

*B. Mobility Challenges*

Several challenges were experienced by the PVI during mobility. This research demonstrates the eight most critical challenges reported by the participants encountered during the interview and observation sessions. All participants explicitly asserted that low awareness of *public behavior* is a severe defect that makes mobility an extreme challenge for PVI. They clarified that sighted people stop on the tactile paving for chatting, park their motorbike on it, and compete to walk on the tactile blocks. Participant P2 expressed:



a) A participant indicates a landmark in a familiar area

b) A participant railing the sidewalk border in an unfamiliar area

Fig. 3. Sample of mobility behaviors.

*"Normal people don't care. We need a minimum level of awareness. I'm not suffering from my blind status; I'm suffering the attitude of people every day and it is stressful."*

Additionally, the presence of different *terrain types* was another significant challenge. All participants reported that potholes, drains, and stairs form a hazard that could directly impact their safety. The participants shared either their personal experiences or friends' stories about falling in potholes and drains. Fig. 4 presents participants while they were addressing different terrain types in the unfamiliar site. Participant P8 stated:

*"The worst thing is falling down in the drain, fall in a drain or a hole."*

Participants’ anxiety and fears were expressed when approaching various terrain types even in the familiar environment, especially potholes that could suddenly appear as a result of weather or constructions. Participants mentioned several other challenges including traffic and crossing the road. Participant P12 expressed,

*"Crossing the road is a big problem ..., crossing the road for the blind is very dangerous."*

The participants lose their direction when they find themselves in a wide area. Crowded places, on the other hand, make them feel uncomfortable and embarrassed, especially if they contact pedestrians with their canes or bodies. Similar feelings were expressed when they approached inaccessible pavements that do not follow the height and width standardization or without tactile paving.

Participant P7 sadly mentioned:

"*I fell before… I didn't know the curb was so high."*

TABLE II. SUMMARY OF MOBILITY BEHAVIORS AND TECHNIQUES PRACTICED DAILY BY THE PVI

| No | Behaviors | Familiar | Unfamiliar | Actions | Emotions |
|---|---|---|---|---|---|
| 1. | Utilize the conventional cane | √ | √ | Contacting the space in front of them to recognize the situation | Confidence |
| 2. | Utilize the cognitive map | √ | | Use environmental objects for real-time awareness | Confidence, pride, anxiety from any changes |
| 3. | Landmarks | √ | √ | Use all senses, improve the cognitive map | Happiness |
| 4. | Accompanying | | √ | Accompany a sighted individual | Sadness, embarrassed, confidence |
| 5. | Go with a group | √ | √ | Group visit to a place | Happiness, confidence |
| 6. | Information collecting | | √ | Ask relatives, use apps. | Confidence, anxiety |
| 7. | Slow walking | | √ | Slow down and be careful | Anxiety, careful |
| 8. | Wide floor-sweeping of the cane | | √ | To recognize the area surrounding their bodies | Anxiety, careful |
| 9. | Talking to the companion | √ | √ | Keep chatting with the companion individual | Confidence |
| 10. | Recognize a change | √ | √ | Stop and scan the cane on the floor widely | Fears, Anxiety |
| 11. | Face obstacles on the head level | √ | | Raise the freehand to the head or face for protecting | Anxiety |
| 12. | Utilize curb and pavements | √ | √ | Utilize foot to determine the height and cane for the width | Careful |
| 13. | Pavement ramp | √ | √ | Looking for, to utilize it | Confidence |
| 14. | Utilize tactile paving | √ | √ | Looking for tactile and walk on it | Confidence, anxiety from any obstacle on it |
| 15. | Ascending/descending staircases | √ | √ | Use foot for the height,<br>rely on handrailing if exist unless use the cane | Anxiety, careful |
| 16. | Walk in a stright line | √ | √ | Tactile paving, keep the cane trail on the sidewalk edge, wall, or road boundary | Happiness |
| 17. | Cross the road | √ | √ | Hearing sense, raise the cane upper than head level. | Fears, stress |
| 18. | Presence of pothole or drain | √ | √ | Use cane to check the depth, diameter, and drain’s cover then avoid | Fears, anxiety, careful |
| 19. | Contact obstacle | √ | √ | Touch by the cane or hand to recognize then avoid | Careful, anxiety |
| 20. | Feel lost | | √ | Ask people, or applications | Fears, stress, sadness |
| 21. | Stop and raise the cane to public | √ | √ | Wait for someone to offer assistance | Embarrassed, anxiety |
| 22. | Alert awareness about a new situation | √ | √ | Stop or slow down, seek for the situation by the cane, recognize the case, tackle it. | Fears, anxiety, careful |

a) Ascending Stairs b. Pothole c. Drain

Fig. 4. Participants addressing va rious terrain types in an unfamiliar area.

Participants were also exposed to obstacles above the ground level such as signboards, open windows, and tree branches

Another critical challenge expressed by participants was public transportation without audio sign. The challenges faced by the PVI are summarized in Table III.

### C. Mobility Aids

This section clarifies the participants' opinions and reliability of the white cane and mobility assistive technologies.

*1) White cane:* The 15 participants in this study emphasized that they rely only on the white cane for mobility. Furthermore, they affirmed that white cane enables them to avoid obstacles, feel safe, and inform the public that they have a vision impairment. Participant P2 said:

*"If there is no cane, I feel something is missing; I feel I am lost."*

However, 11 participants argued that the white cane also has its limitations and it does not provide 100% safe mobility. Some of the limitations that participants shared include lacking the ability to recognize the obstacle, detecting small terrain types, and detecting obstacles above the ground level. Therefore, the participants expressed a desire to have additional aid to overcome the limitations. Participant P7 remarked,

*"It is quite safe. I mean, if you're in a familiar place, it's quite safe but in an unfamiliar place, maybe a bit risky."*

TABLE III. SUMMARY OF MOBILITY CHALLENGES EXPERIENCED BY THE PVI

| No. | Challenge | Familiar | Unfamiliar | Actions | Emotions |
|---|---|---|---|---|---|
| 1. | Public Attitude | √ | √ | Stop on the tactile paving for chatting. Park motorbike on it. Walk on the tactile blocks. Ignore PVI | Sadness, anger, stress |
| 2. | Terrain types | √ | √ | Presence of Pothole, drain, stairs<br>Lack of standard stairs, curbs and pavements<br>Lack of handrailing of staircase | Fears, sadness, anxiety |
| 3. | Traffic | √ | √ | Cross the road | Fears, anxiety |
| 4. | Wide area | √ | √ | Lost direction, ask people | anxiety |
| 5. | Strangers | √ | √ | Ask strangers for help, | Fears, anxiety |
| 6. | Inaccessible pavement | √ | √ | Pavement without tactile block.<br>Not standard heigh and width<br>Obstacles, rubbish, motorbike | Sadness, anxiety |
| 7. | Obstacles above the ground level | √ | √ | Strike upper body parts like chest, face, and head. Signboards, tree branches, open windows, hanging obstacles. | Fears, sadness, anxiety |
| 8. | Public transportation | √ | √ | Visual signs, gap between the train and its platform | Fears, sadness, anxiety |

Participant P15 rated safe mobility using the white cane to range from 70 to 75%. This is not surprising as several researchers verified the limitations of the white cane [24], [3].

*2) Assistive technologies:* In terms of the reliability of the ATs for PVI, all participants responded that they do not rely on any existing AT from either electronic devices or apps. Several researchers [1], [25] reported that PVI trust the white cane because of its cost-effectiveness and provision of better performance compared to smart canes.

None of the 15 participants utilized any mobile electronic device in their daily life. They justified that absence of usage of ATs by expensive, have low performance, are heavier compared to the white cane, and cause anxiety about the battery draining.

Regarding the use of mobile apps, 13 participants owned smartphones and use social media but none of them relied on apps during mobility. Nevertheless, six participants employed Maps apps, Waze [26], Lazarillo [27], and Moovit [28] to collect data before the trip.

Although some of the participants do not rely on mobile Apps, they opined that apps could satisfy some of their desired features. For instance, App can function as complementary with the white cane. Since the users already own a smartphone, the App can be installed and eliminates the need to purchase a new device, which making App an affordable option. Additionally, apps/smartphones do not attract unwanted attention and could be used for multimodal feedback. Apps are usually free or may incur a low cost compared to gadget ATs. However, the participants expressed their reasons for not using Apps during navigation which included the hazard of holding a smartphone when walking, the importance of having a free hand for safe mobility, and the need for an internet connection.

### *D. Perception of PVI for New AT Features*

The appropriate mobility AT for PVI depend on the user's personality and activities [29]. However, the information gathered in this study included the most obvious participants' preferences according to AT features that may address their requirements and gain acceptance from the perspective of design, feedback, and distance to reach the obstacle.

Several designs were selected by the participants in terms of the AT *features*. All participants preferred a solution that is less obvious and does not attract pedestrian attention. This is consistent with the findings of [30], [10] that emphasized the rejection of any design that advertises the disability and attracts unwanted attention. Participant P1 reported;

*"I do not want something obvious. It shouldn't make it as an alien."*

Eight participants selected the smart cane as the preferred design, whereas two participants preferred wearable devices, such as eyeglasses or a jacket in addition with the conventional cane. Two participants selected a mobile application solution, but again accompanied by the conventional cane. In contrast, the remaining three participants reported that they do not trust any type of AT and preferred to stick with the conventional white cane, indicating a resistance to change.

According to the *feedback*, the study emphasized that it should be conveyed in real-time and precise in terms of the obstacle name and distance (e.g., pothole, 2 meters). The majority of respondents (n = 14) stated that the speech message is the best feedback type because it provides a good perception and enables them to recognize their environment. Additionally, three participants mentioned the importance of vibration especially in a noisy environment. Each feedback style has its advantages and disadvantages. Audio provides rich interaction spatial information that lets the user visualize the environment [31]. Which can improve the cognitive map also [23] but it might be missed in a noisy environment [14]. In contrast, haptic feedback provides privacy, however, the spatial information is limited [32]. Thus, this study agrees with some earlier reports discussing the functionality of multimodality feedback, (i.e., speech message and vibration). Multimodality provides better interaction modes and improves the proposed solution durability, flexibility, and accessibility for a wider range of acceptance [31], [33].

Information was also gathered in this study about the required *coverage distance* to reach the obstacle. Surprisingly, most participants were less informed about the distance units and unable to recognize how the distance is measured in meters following the usage of their arms to specify a given distance. Seven participants mentioned that it should neither be too close nor too far. They added that they needed enough time to prepare themselves for the new situation without losing it. The responses were between 0.5 to 4 meters with a mean of 2.25 meters, which approximately validates the coverage distance reported in various studies ranging from 2 to 4 meters, [2], [34]. The participants' preferences for the main features of the future AT are summarized in Table IV.

## V. Discussion and Recommendations

This study was conducted to provide comprehensive information about mobility context that developers need to consider when developing new mobility ATs for the PVI. A qualitative study involved 15 participants with vision impairment, collected information about outdoor mobility, behaviors, challenges, and the preferred AT features.

An interesting finding demonstrated that PVI who either had solid mobility experience were able to safely address various mobility situations via the white cane only. However, the mobility hazards faced by the PVI were primarily from a lack of spatial information about the environment in front of them. For instance, the cane may miss between its up-down or left-right movement when approaching potholes, short stairs, as well as obstacles above the ground level such as tree branches. These events reflect the increased risk of PVI to various hazards resulting from a lack of spatial information and awareness.

Another significant findings is that PVI were unable to navigate without a cane, similar outcomes have been reported in previous studies [29], [35], [1]. Based on these findings, this study highlights the necessity of an AT that works as a complementary to the cane and address its limitations. A previous study also presented a similar complementary function between the conventional cane with wayfinding apps [19].

In terms of mobility behaviors, the study highlights the role of the cognitive map in performing safe and independent mobility in a familiar environment. The superiority of employing the cognitive map was evident when comparing mobility tasks in familiar and unfamiliar environments. This study encourages AT developers to prioritize the improvement of the cognitive map as a mobility aid, besides the most current research that solely focuses on addressing instant mobility.

In contrast, PVI primarily relied on accompanying a sighted individual when they visit an unfamiliar environment. However, they also depended on various techniques such as gathering information about the route and the area they intent to visit and trailing along a wall or a sidewalk border, which were also reported in a previous study [36]. Likewise, the PVI stopped when they feel a change of the ground surface until they recognize the situation, and they walk slowly and sweep the cane widely. The study suggests that these mobility behaviors need to be considered by the AT developers when designing future ATs. For instance, users could be directed to the nearest wall or sidewalk edge for it to be utilized for straight-line walking.

An unexpected challenge emerging from this study was the frequent suffering of PVI from the attitude of a large number of sighted individuals who compete with them to utilize infrastructures specially designed for PVI, including tactile blocks. Additionally, other challenges were reported by participants including, the presence of different types of terrain, crossing the road, navigating in wide areas, and obstacles above the ground level, inaccessible pavements in terms of height, width, and lack of tactile paving, and using public transportation. This indicates the need for ATs to tackle these barriers, especially from the aspects of detection performance, usability, and cost.

In terms of AT design preferences, again the significance of the cane was obvious, where most participants preferred utilizing the conventional cane with another assistance (i.e., app or wearable device). This leads to recommend the developers to adopt the complementary function between AT and the conventional cane, thereby eliminating the idea of substituting the cane with another AT.

For the feedback, 93.3% of participants prefer speech messages, however audio could be missed in a noisy environment. Therefore, the study suggests providing multimodal feedback (haptic and audio), which improves flexibility, usability and enhances the acceptance of the solution.

TABLE IV. SUMMARY OF THE PREFERENCES OF FUTURE AT FEATURES

| Feature | Preference | Advantage | Disadvantage |
|---|---|---|---|
| Design | Smart cane | Still utilize a cane | Heavyweight compared to the white cane, costly, anxiety for the battery draining |
| | Mobile app | No more device, installed in their smartphones | Using smartphone during the navigation |
| | Not obvious, small size | Do not attract public attention, can be hanged, keep one hand free | |
| | Affordable | Able to purchase and try even they do not trust technology | |
| | Lightweight | Comfortable as the white cane | |
| Feedback | Precise amount | Simple, specific, and direct information | |
| | Speech message | Rich information to recognize the situation, improve the cognitive map | Loss in a noisy environment, block surrounding sounds |
| | Vibration | Can be used in noisy areas, provides privacy | Limited information, confusing |
| Coverage Distance | Around 2.5 meters | Enough time to prepare themselves for the new situation | |

According to the coverage distance to convey the feedback, the findings showed that 2 to 3 meters is sufficient distance for the users to recognize the change and prepare themselves for the new situation.

## VI. CONCLUSION AND FUTURE WORK

The purpose of the current research is to provide comprehension of the outdoor mobility behaviors, challenges, and the target group's perceptions of the solution. The research confirms previous findings and contributes to our understanding of the new mobility context.

The study answered the research questions by elaborating on the behaviors and challenges of PVI mobility, in addition to clarifying the ATs features that fulfill the PVI expectations. The findings demonstrated that PVI are able to navigate safely when they are informed about the environmental situation within a sufficient time. Also, the white cane is a primary mobility tool for PVI and any other assistant could be used as a complementary. Hence, it is suggested that the designers develop mobility ATs that work with the white cane and not substitute it. The results also emerge lack of spatial information and lack of public awareness as significant factors that increase mobility difficulty. The study reported perception of the new AT requirements. The results revealed the preference of the cane design, multimodal feedback, and two meters coverage distance to reach the obstacle. For future work, the authors intend to propose a prototype of AT to support outdoor mobility systems and meet the participants' requirements and perceptions based on the findings in this study.

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